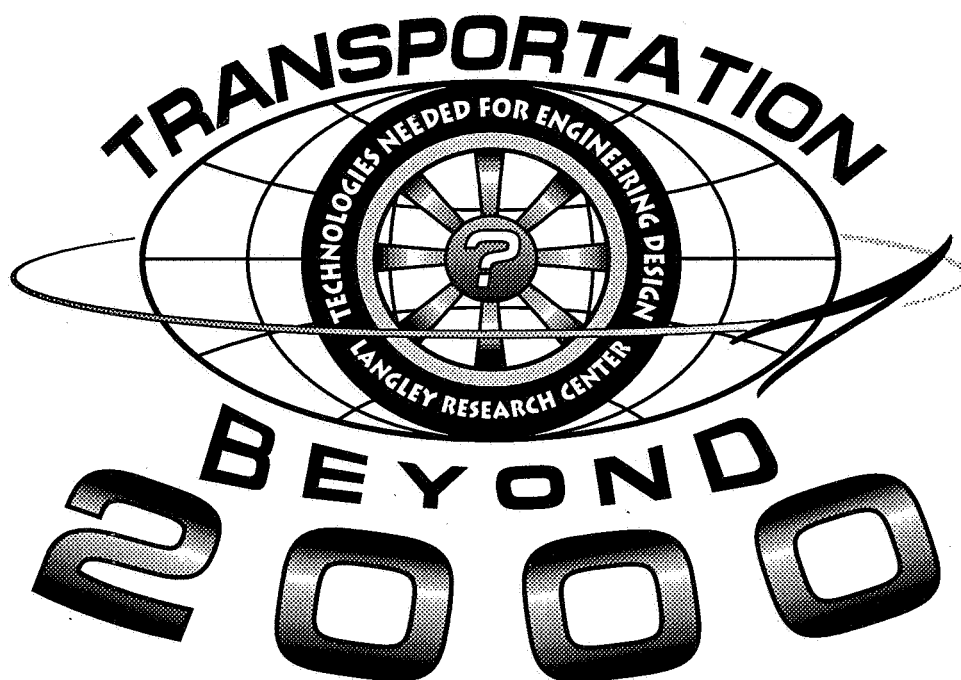




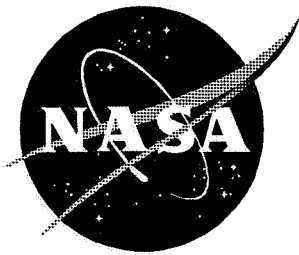
NASA Conference Publication 10184
Part 1

Transportation Beyond 2000: Technologies Needed for Engineering Design



Proceedings of a workshop sponsored by the
National Aeronautics and Space Administration
and held at Langley Research Center,
Hampton, Virginia
September 26-28, 1995

February 1996



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Transportation Beyond 2000: Technologies Needed for Engineering Design

Compiled by

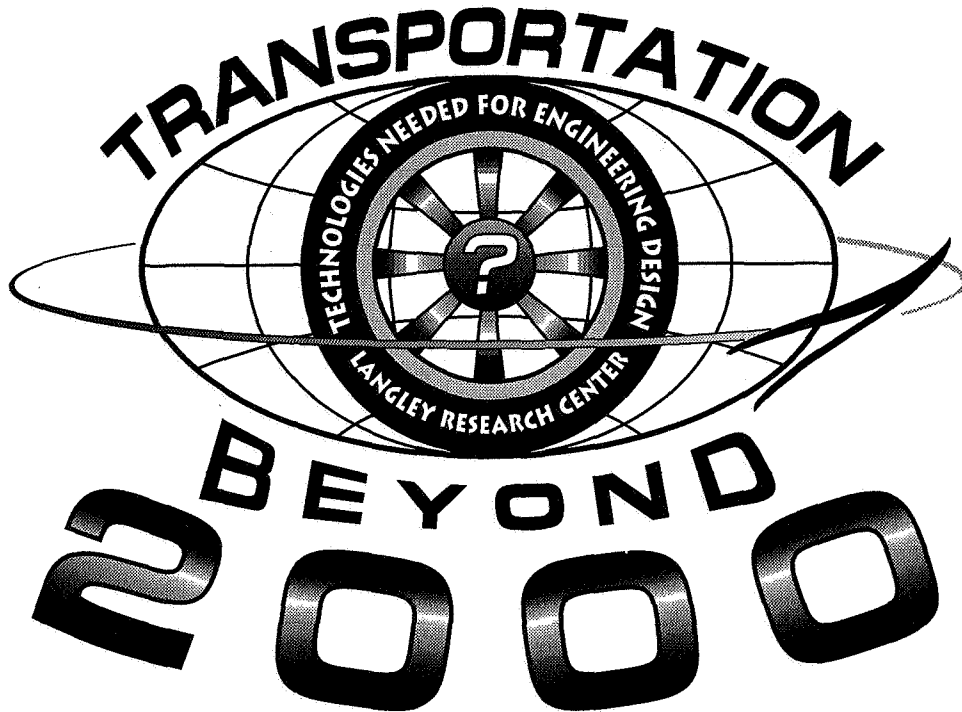
*Lawrence D. Huebner, Scott C. Asbury, John E. Lamar, Robert E. McKinley, Jr., Robert C. Scott,
William J. Small, and Abel O. Torres
Langley Research Center • Hampton, Virginia*

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National Aeronautics and Space Administration
Langley Research Center • Hampton, Virginia 23681-0001

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About the Logo



The logo depicts the broad range of transportation discussed at the workshop, including the first revolutionary transportation innovation, the wheel, and the winged vehicle from the NASA logo orbiting the earth. The question mark at the center of the logo depicts the mystery of the transportation concepts that will be available to us and future generations.

Workshop Video Information

The entire workshop was videotaped for archival purposes and is available for loan or duplication. For viewing or checkout, contact the NASA Langley Library at Mail Stop 185. For duplication, contact the Video Production Group at Mail Stop 425A.

Table of Contents

Title Page	i
About the Logo	ii
Workshop Video Information	ii
Table of Contents	iii
Foreword	iv
Workshop Sponsor, Langley Senior Scientist Dennis M. Bushnell	
Preface	v
Langley Aeronautics Technical Committee	
Acknowledgments	vii
Workshop Program	viii
Presentation Abstracts	xii
Speaker Information	xxii
Presentation Hardcopies	1
Session 1: Historical Background and General Future Perspective	1- /
Session 2: Personal Travel	111
Session 3: Mass Transportation	211
Session 4: Advanced Technologies for Future Transportation Concepts	509
Transcription of Wrap-up Panel Discussion (Session 5)	703

Foreword

One of the defining characteristics of humankind is the simultaneous blessing and curse of considering the future. As we currently understand the situation, other animals dwell exclusively in the present (except for some instinctive activities). In the current post-cold-war scenario of global “economic warfare” and in a world where other nations plan long term, the U.S. must actively work longer term technology requirements and capability projections in the economic arena to the same or greater extent to what was so successfully done in the military arena during the Cold War.

This workshop constitutes a contribution toward such planning in the transportation sector of the economy. The results of this workshop indicate that virtual revolutions in physical transportation are required by society and will be enabled by technology either in the research pipeline or envisaged as being within the “Frontiers of the Responsibly Imaginable.”

Dennis M. Bushnell
Langley Senior Scientist
Workshop Sponsor

Preface

The "Transportation Beyond 2000: Technologies Needed for Engineering Design" workshop was held at the NASA Langley Research Center during September 26-28, 1995, under the sponsorship of the Langley Aerodynamics Technical Committee and the Langley Senior Scientist. The purpose of the workshop was to acquaint the staff of the NASA Langley Research Center with the broad spectrum of transportation challenges and concepts foreseen within the next 20 years. The hope is that material presented at the workshop and contained in this document will stimulate innovative high-payoff research directed toward the efficiency of future transportation systems.

This workshop was a bit unusual in that it consisted entirely of invited presentations of advanced transportation concepts and technologies in the context of future needs for the total transportation system. Insofar as possible, the speakers were from outside Langley.

The workshop included five sessions designed to stress the changing environmental, social, and technological factors that will lead to a revolution in the way we will travel in the 21st century. This revolution will encompass land, air, and space vehicles and will include non-conventional electronic virtual travel. The first session provided the historical background and a general perspective for future transportation, including emerging transportation alternatives such as working at a distance. Personal travel was the subject of Session Two. The third session looked at mass transportation, including advanced rail vehicles, advanced commuter aircraft, and advanced transport aircraft. The fourth session addressed some of the technologies required for the above revolutionary transportation systems to evolve. The workshop concluded with a wrap-up panel discussion, Session Five.

The topics presented herein all have viable technical components and are at a stage in their development that, with sufficient engineering research, one or more of these could make a significant impact on transportation and our social structure.

As previously noted, the goal of the Transportation Beyond 2000 Workshop was to stimulate NASA Langley's research community and encourage them to apply their expertise to innovative high-payoff transportation research. Over 200 Langley personnel attended the 2.5-day workshop, and most attendees spoke positively of the program and speakers. Most participants indeed felt quite inspired by the topics discussed. As in all meetings, the organizers learn afterwards that some key element of the workshop subject was inadvertently overlooked. This advanced transportation workshop was no exception, and the topics of water transportation and high-speed light rail were two that were pointed out by participants. The otherwise favorable comments and overall high level of interest illustrate the need for NASA Langley to pursue

transportation systems research, as well as a need to get the workshop information out to as many researchers as possible.

Now that the workshop itself is over, there is the need to keep alive the ideas presented in order that the purpose of the meeting may not be lost. To emphasize this point, consider the following comment from the panel discussion at the end of the workshop:

“. . . I think there is one flaw in the NASA program at this point, and that is in the commuter area. We pat ourselves on the back on the positive balance of trade, but in the 30 to 100 seat commuter there is a negative one billion dollar balance of trade in this country. We are losing a billion dollar market and we don't have a single company in that market. None! We gave it up. NASA did a good study in 1982 on that subject, the Stack report. We sometimes do a very good job of saying what we should do and then we don't follow through. So we gave up that billion dollars, so let's not do it in the other areas as well. Let's listen to what we are saying, and let's go do it.” (Steve Justice, Lockheed-Martin, 9/28/95.)

To this end, three actions have been undertaken. The first is this conference publication of the workshop proceedings. The second is the placement of the video recordings of the presentations and the panel discussion taken during the workshop in the NASA Langley Research Center's Learning Center where they are available for loan and/or viewing. The third is to stimulate transportation-related breakthroughs from within Langley's research community.

Langley Aerodynamics Technical Committee

Acknowledgments

The preparation for a workshop intended for the entire staff of the Langley Research Center involved much coordination and assistance from personnel outside the Langley Aeronautics Technical Committee. A number of individuals were instrumental in the success of the workshop, and they are cited below for their efforts:

Thomas Brinkley	Proceedings Publications Guidance
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Rhonda Toomer	Registration/Sign-In Desk Assistance
Pamela Verniel	Organization of Workshop Venue
and staff at the H. J. E. Reid Conference Center	
Susan Walters	Workshop Agenda Viewgraphs Generation
Cathy Watson	Public Affairs Coordination
Patricia E. J. Williams	<i>LaRC This Week</i> Editor

Finally, without the support and encouragement from the Langley Senior Scientist, Mr. Dennis M. Bushnell, this workshop would surely not have taken place and been as successful as it turned out to be.

Workshop Program

September 26, 1995

8:30-8:45 **Welcoming Remarks**, Roy V. Harris, Jr., NASA Langley
Research Center Assistant Director for Research and
Engineering

8:45-9:00 **Opening Remarks/Introduction of LATC Members**,
William J. Small, LATC Chairman

Session 1: Historical Background and General Future Perspective. *omit*
Chairman: Dr. John E. Lamar

9:00-10:00 **The History of Transportation, With a Peek Into the Future**, *-1*
Dr. John D. Anderson, Jr., University of Maryland

10:00-10:15 **BREAK**

10:15-11:15 **In Search of Cybernautics**, Prof. Steven C. Crow, *-2*
University of Arizona

11:15-12:15 **The New Organization: Rethinking Work in the Age of** *-3*
Virtuosity, Duncan B. Sutherland, The Sutherland Group, Inc.

12:15-1:15 **LUNCH**

Session 2: Personal Travel. *-omit*
Chairman: Scott C. Asbury

1:15-1:45 **The Future of Transportation in Society: Forces of Change**, *-4*
Dr. Barbara C. Richardson, Transportation Research Institute,
University of Michigan

1:45-2:15 **The Smart Highway Project: Smart Highways, Smart** *-5*
Vehicles, Smart Engineering, Ray D. Pethtel, Virginia
Polytechnic Institute and State University

2:15-3:00 **Hypercars: The Next Industrial Revolution**, *-6*
Dr. Amory B. Lovins, Rocky Mountain Institute

3:00-3:15 **BREAK**

3:15-3:45 **Flying Cars**, Prof. Steven C. Crow, University of Arizona *-7*

Session 3: Mass Transportation.

Chairman: Abel O. Torres

- 3:45-4:15 **Aerodynamics of MAGLEV Trains**, Dr. Joseph A. Schetz and Dr. James F. Marchman III, Virginia Polytechnic Institute and State University -8
- 4:15-4:45 **Magnetic Levitation Systems for Future Aeronautics and Space Research and Missions**, Dr. Isaiah M. Blankson and John C. Mankins, NASA Headquarters 9

September 27, 1995

Session 3: Mass Transportation (Continued). omit

Chairman: Robert E. McKinley

- 8:15-8:45 **Far Term Visions in Aeronautics**, Dennis M. Bushnell, NASA Langley Research Center -10
- 8:45-9:15 **History, A Projection of the Future: A Rotary Wing Perspective**, Robert J. Huston, Distinguished Research Associate, NASA Langley Research Center -11
- 9:15-9:45 **Highly Nonplanar Lifting Systems**, Dr. Ilan Kroo, Stanford University -12
- 9:45-10:15 **The Application of Pneumatic Lift and Control Surface Technology to Advanced Transport Aircraft**, Robert J. Englar, Georgia Tech Research Institute -13
- 10:15-10:30 **BREAK**
- 10:30-11:00 **The Future of Very Large Air Transport Vehicles: A Lockheed Martin Perspective**, R. Steven Justice, Anthony P. Hays, and Ed L. Parrott, Lockheed Martin Aeronautical Systems -14
- 11:00-11:30 **Evolution of the Revolutionary Blended-Wing-Body Subsonic Transport**, Dr. Robert H. Liebeck, Mark A. Page, and Blaine K. Rawdon, McDonnell Douglas Aerospace -15
- 11:30-12:00 **Large Capacity Oblique All-Wing Transport Aircraft**, Thomas L. Galloway, James Phillips, NASA Ames Research Center, Mark Waters, Eloret Institute, and Robert Kennelly, Jr., NASA Ames Research Center 16
- 12:00-12:30 **A Corporate Supersonic Transport (CST)**, Randall Greene, Aeronautical Systems Corp., and Dr. Richard Seebass, University of Colorado 17

Session 4: Advanced Technologies for Future Transportation Concepts.

Chairman: Robert C. Scott

- 1:30-2:00 ***Integrated Airframe Technology: The Future of Advanced Composites***, David F. Taggart, Lockheed Martin Skunk Works
- 2:00-2:30 ***Fuel Cells for Transportation: Status and Technical/Economic Needs***, Glenn Rambach, Lawrence Livermore National Laboratory
- 2:30-3:00 ***Hypersonic Airbreathing Vehicles/Technologies***, James L. Hunt, NASA Langley Research Center
- 3:00-3:15 **BREAK**
- 3:15-3:45 ***The Use of Steady and Pulsed Detonations in Propulsion Systems***, Dr. Henry G. Adelman, Thermosciences Institute, Gene P. Menees, NASA Ames Research Center (retired), Dr. Jean-Luc Cambier, Thermosciences Institute, and Jeffrey V. Bowles, NASA-Ames Research Center
- 3:45-4:15 ***A Pre-Mixed Shock-Induced-Combustion Approach to Inlet and Combustor Design for Hypersonic Applications***, John P. Weidner, NASA Langley Research Center

September 28, 1995

Session 4: Advanced Technologies for Future Transportation Concepts (Continued).

Chairman: Lawrence D. Huebner

- 8:15-8:45 ***Energy Beam Highways Through the Skies***, Dr. Leik N. Myrabo, Rensselaer Polytechnic Institute
- 8:45-9:15 ***High Energy Density Matter for Rocket Propulsion***, Dr. Patrick G. Carrick, Phillips Laboratory, Edwards AFB
- 9:15-9:45 ***Fusion Power and Propulsion for Future Flight***, H. David Froning, Jr., Flight Unlimited
- 9:45-10:15 ***Advanced Space Propulsion***, Dr. Robert H. Frisbee, Jet Propulsion Laboratory
- 10:15-10:30 **BREAK**

Session 5: Wrap-Up Panel Discussion.

Moderator: William J. Small

10:30-12:00 Participants:

Dr. John D. Anderson, Jr.

Dennis M. Bushnell

Prof. Steven C. Crow

George Finelli

H. David Froning

Dr. Ilan Kroo

Dr. Robert H. Liebeck

12:00 **ADJOURN**

Presentation Abstracts

① ***The History of Transportation, With a Peek Into the Future***, Dr. John D. Anderson, Jr., University of Maryland

In the first part of this presentation, a general historical review of the heydays of various modes of transportation will be given, where "heydays" will be interpreted as periods of fundamental technological development. With this as background, focus will then be placed on the airplane -- the mode of transportation that has changed the world in the 20th century, and which in the minds of many has been the most important technological development in this century. The technical history of air transportation (the airplane) will be reviewed, with special emphasis on the aerodynamic evolution of the airplane. Some specific examples of pivotal technical advances (and breakthroughs) from the history of applied aerodynamics will be discussed. Finally, this historical perspective will be used to help us peek into the future of transportation in the 21st century.

② ***In Search of Cybernautics***, Prof. Steven C. Crow, University of Arizona

This is a talk about the future of aviation in the information age.

Ages come and go. Certainly the atomic age came and went, but the information age looks different. Microprocessor speeds have increased by a multiple of 25,000 since their introduction a quarter century ago, a rate of 50% each year, with no sign of slowing. The personal computer on my desk can process data about as fast as my eyes, maybe almost as fast as my brain, but my computer is nearly blind and deaf and has a random access memory span of only 0.07 seconds.

My computer can fly an airplane though. The data rate to process twelve state variables and four controls is 2.56 Kbps (kilo bits per second), and the bandwidth to monitor all variables of 100 airplanes in the neighborhood is 16 KHz, about the same as presently used for voice communications. The Global Positioning System with various enhancements can provide all of the state variables.

The talk reviews some recent experiments on navigation and control with the Global Positioning System. Vertical position accuracies within 1 foot have been demonstrated in the most recent experiments, and research emphases have shifted to issues of integrity, continuity, and availability. Inertial navigation systems (INS) contribute much to the reliability of GPS-based autoland systems. The GPS data stream can cease, and INS can still complete a precision landing from an altitude of 200 feet.

The future of aviation looks like automatic airplanes communicating among each other to schedule ground assets and to avoid collisions and wake hazards. The business of the FAA will be to assure integrity of global navigation systems, to develop and maintain the software rules of the air, and to provide expert pilots to handle emergencies from the ground via radio control.

The future of aviation is democratic and lends itself to personal airplanes. Some data analyses reveal that personal airplanes are just as efficient as large turbofan transports and just as fast over distances up to 1,000 miles, thanks to the decelerative influence of the hub and spoke system. Maybe by the year 2020, the airplane will rank with the automobile and computer as an agent of personal freedom.

③ ***The New Organization: Rethinking Work in the Age of Virtuosity***, Duncan B. Sutherland, The Sutherland Group, Inc.

Like two enormous steam engines, throttles wide-open, bells clanging and whistles screeching, careening toward each other down the same track, two powerful forces are about to collide and the point of collision will be smack in the middle of the white-collar workplace. Moreover, once the dust has settled, it is quite likely that we will never be able to think about the white-collar workplace in quite the same way again.

The forces couldn't be more different. One force, the theory of complex adaptive systems, has its roots in the radical new sciences of chaos and complexity. The other force, the notion of organizations being learning systems, more like living organisms than "information factories," is

an outgrowth of the new management thinking of leading organizational theorists like the Claremont Graduate School's Peter Drucker, MIT's Peter Senge, and Hitotsubashi University's Ikujiro Nonaka. Nevertheless, both the new science and the new management thinking seem to point to a similar and perhaps even startling conclusion: the business organization of the 21st century will look nothing like the bureaucratic organizational model that prevails in most companies today, a model that has remained largely unchanged since the manufacturing heydays of 1950s.

While the details of the new organization remain sketchy, its rough outline is already beginning to take shape. Rather than simply being flatter through the elimination of layer upon layer of "middle management," the new organization is likely to be made up of networks of specialists who will be, for all practical purposes, self-managing. Rather than focusing on issues like re-engineering business processes, a holdover from Taylorism, the focus will be on supporting the continuous learning of an organization's specialists, the sharing of this learning with other specialists, and the embedding of this learning in the organization's physical structure. Finally, rather than viewing themselves as going through relatively long periods of stability punctuated by shorts bursts of "reorganization," business enterprises will come to realize that their very survival depends upon their being in a state of continuous organization.

The implications of the new organization with respect to how companies approach the planning, design, and management of the technology infrastructure that enables individual learning, self-management, and continuous organization, are both numerous and far-reaching. As part of this technology infrastructure, the white-collar workplace exists in the form it does today as a direct result of management's beliefs about how time, space, and tools ought to be organized and managed in order to accomplish useful intellectual work. Obviously, if these beliefs change radically, as both the new science and the new management thinking suggest is about to happen, then it is almost inevitable that the form and function of the white-collar workplace will change radically, as well. Will there even be a white-collar workplace in the 21st century, in the sense of purpose-built facilities designed to support the co-location of large numbers of white-collar workers? Only time will tell. However, the leading indicators seem to suggest that, as the old saying goes, "We ain't seen nothin' yet!"

④ ***The Future of Transportation in Society: Forces of Change***, Dr. Barbara C. Richardson, Transportation Research Institute, University of Michigan

The transportation system is a critical element of the social/political/economic system of the United States. Factors influencing the use of transportation technology include technology push, market pull, and external factors. In order for new transportation technology to be successful, it must meet the needs of the market. These needs are diverse and vary almost by individual.

Historical trends show great changes in transportation use by mode and origins and destinations of trips. Other important changes in society affecting transportation use include changes in the composition of society by gender, age, national origin, family composition, land use, income, and residential distribution. Changes of these factors in the future and how technology is deployed to meet the changing needs of society will affect the success of transportation technology implementation over the next twenty years.

⑤ ***The Smart Highway Project: Smart Highways, Smart Vehicles, Smart Engineering***, Ray D. Pethtel, Virginia Tech

The Smart Highway project is a six mile, limited access roadway being built between Interstate 81 and Blacksburg, Virginia. The initial construction segment will be two miles long and is designed to serve as a test bed and test track for Intelligent Transportation Systems (ITS) research. The Center for Transportation Research (CTR) at Virginia Tech is developing three evaluation tools for its ITS research including DYNVIMTS (a software framework), and the FLASH Lab (a 1/15th scale model highway and vehicle system). The Smart Highway rounds out the Center's evaluation methodology by allowing full scale operational tests, evaluations, and research under both experimental and conventional traffic conditions.

Currently under development is a concept for a fully automated highway using a

"Cooperative Infrastructure Managed System" which involves ultra wide band communication beacons installed in the infrastructure with appropriate sensors, receivers and processors on board the vehicles. The project is part of the research program funded by the National Automated Highway System Consortium. The CTR hopes to develop the automated concept to prototype status by 1997. Other smart transportation and smart engineering concepts are proposed.

This presentation will address the goals and objectives of the Smart Highway project, overview its status and importance to the region, and identify some of the transportation technology now under development and planned in the future.

② **Hypercars: The Next Industrial Revolution**, Dr. Amory B. Lovins, Rocky Mountain Institute

The auto industry--one-seventh of the GNP, and the highest expression of the Iron Age--is about to trigger the biggest transformation in industrial structure since the microchip. Ultralight cars molded from net-shape advanced composites can be severalfold lighter than present steel cars, yet safer, sportier, and more comfortable, durable, and beautiful. Modern hybrid-electric drives boost efficiency ~1.3-1.5x in heavy steel cars, but ~ 5-20x in ultralight, very slippery platforms. Synergistically combined into ultralight-hybrid "hypercars," these elements can yield state-of-the-shelf family cars that average 150-300+ mi/gal--twice that with state-of-the-art technologies--yet can also be superior in all other respects, probably including cost: carbon-fiber monocoques can actually be cheaper to mass-produce than steel unibodies.

Designing cars more like aircraft and less like tanks requires not only a ~400-500 kg curb mass and very low air and road drag, but also an aerospace philosophy of engineering integration. Mass, cost, and complexity turn out to compound with heavy hybrids but to decompound with ultralight hybrids, owing partly to radical simplification. Excellent aerodynamics, preferable including advanced techniques for passive boundary-layer control, will be the key to successful design integration.

Transforming automaking is a competitive and environmental imperative, could form the nucleus of a green industrial Renaissance, and would enhance national security by, among other things, saving as much oil as OPEC now extracts. However, this transformation faces serious cultural barriers. For example, hypercars will be more like computers with wheels than like cars with chips--they'll have an order of magnitude more code than today's cars--but Detroit is not a software culture. Just the transition from stamped and welded steel to integrated and adhesive-joined synthetics is difficult enough.

Nonetheless, hypercars are rapidly heading to market in the late 1990s, because ~25 current and intending automakers are eager to capture their potentially decisive competitive advantages--including order-of-magnitude reductions in product cycle time, tooling cost, assembly effort, and parts count. Hypercars will succeed, and may well sweep the market, not because of mandates or subsidies, but because of manufacturers' quest for competitive advantage and customers' desire for better, smarter cars.

② **Flying Cars**, Prof. Steven C. Crow, University of Arizona

Flying cars have nearly mythical appeal to nonpilots, a group that includes almost the whole human race. The appeal resides in the perceived utility of flying cars, vehicles that offer portal-to-portal transportation, yet break the bonds of road and traffic and travel freely through the sky at the drivers will. Part of the appeal is an assumption that flying cars can be as easy to fly as to drive.

Flying cars have been part of the dream of aviation since the dawn of powered flight. Glenn Curtiss built, displayed, and maybe even flew a flying car in 1917, the Curtiss Autoplane. Many roadable airplanes were built in the 1930's, like the Waterman Arrowbile and the Fulton Airphibian. Two flying cars came close to production in the early 1950's. Ted Hall built a series of flying cars culminating in the Convaircar, sponsored by Consolidated Vultee, General Motors, and Hertz. Molt Taylor built and certified his Aerocar, and Ford came close to producing them. Three Aerocars are still flyable, two in museums in Seattle and Oshkosh, and the third owned and flown by Ed Sweeny.

Flying cars do have problems, which so far have prevented commercial success. An obvious

problem is complexity of the vehicle, the infrastructure, or both. Another is the difficulty of matching low power for normal driving with high power in flight. An automobile uses only about 20 hp at traffic speeds, while a personal airplane needs about 160 hp at speeds typical of flight. Many automobile engines can deliver 160 hp, but not for very long.

A more subtle issue involves the drag of automobiles and airplanes. A good personal airplane can fly 30 miles per gallon of fuel at 200 mph. A good sports car would need 660 hp at the same speed and would travel only 3 miles per gallon. The difference is drag area, about 4.5 sq ft for the automobile and 1.4 sq ft for the airplane. A flying car better have the drag area of the airplane, not the car!

⑧ **Aerodynamics of MAGLEV Trains**, Dr. Joseph A. Schetz and Dr. James F. Marchman III, Virginia Tech

High-speed (500 kph) trains using magnetic forces for levitation, propulsion and control offer many advantages for the nation and a good opportunity for the aerospace community to apply "high tech" methods to the domestic sector. One area of many that will need advanced research is the aerodynamics of such MAGLEV vehicles. There are important issues with regard to wind tunnel testing and the application of CFD to these devices.

This talk will deal with the aerodynamic design of MAGLEV vehicles with emphasis on wind tunnel testing. The moving track facility designed and constructed in the 6 ft. Stability Wind Tunnel at Virginia Tech will be described. Test results for a variety of MAGLEV vehicle configurations will be presented.

The last topic to be discussed is a Multi-disciplinary Design approach that is being applied to MAGLEV vehicle configuration design including aerodynamics, structures, manufacturability and life-cycle cost.

⑨ **Magnetic Levitation Systems for Future Aeronautics and Space Research and Missions**, Dr. Isaiah M. Blankson and John C. Mankins, NASA Headquarters

The objectives, advantages, and research needs for several applications of superconducting magnetic levitation to aerodynamics research, testing, and space-launch are discussed. Applications include very large-scale magnetic balance and suspension systems for high alpha testing, support interference-free testing of slender hypersonic propulsion/airframe integrated vehicles, and hypersonic maglev. Current practice and concepts are outlined as part of a unified effort in high magnetic fields R&D within NASA. Recent advances in the design and construction of the proposed ground-based Holloman test track (rocket sled) that uses magnetic levitation are presented. It is projected that ground speeds of up to Mach 8 to 11 at sea-level are possible with such a system. This capability may enable supersonic combustor tests as well as ramjet-to-scramjet transition simulation to be performed in clean air. Finally a novel space launch concept (Maglifter) which uses magnetic levitation and propulsion for a re-usable "first stage" and rocket or air-breathing combined-cycle propulsion for its second stage is discussed in detail. Performance of this concept is compared with conventional advanced launch systems and a preliminary concept for a subscale system demonstration is presented.

⑩ **Far Term Visions in Aeronautics**, Dennis M. Bushnell, NASA Langley Research Center

Lecture discusses envisaged advanced concepts across the speed range including VTOL converticars (personal air transportation), advanced subsonic and supersonic long haul transports, hypersonic transports, and developments/applications of flow control technology. In most cases, these concepts and approaches offer at least the potential of 100 percent improvements in various performance metrics and, in some cases, far more. Special emphasis is given to advanced CTOL configurations which may offer simultaneous opportunities for mitigation of both drag-due-to-lift and wake vortex hazard and to synergistic propulsive and aerodynamic interactions.

Lecture concludes that a virtual revolution in the civilian aeronautical world is conceivable as a result of technology maturation in several areas which could enable the exploitation of "end-point" designs.

11 **History, A Projection of the Future: A Rotary Wing Perspective**, Robert J. Huston, DRA, NASA Langley Research Center

The success and failure of past vehicle concepts is reviewed in an attempt to highlight some critical issues for future aircraft development. It is the contention of the author that many of the advanced vehicle concepts attempted in the past failed because of a lack of appreciation, by both the sponsors and the developer, for the technical and societal requirements critical to their success. This paper will review the history of some attempts to provide both good hover and forward flight efficiency and will point out some of the technical and societal obstacles encountered. Two examples, that of the tiltrotor and tiltwing vehicles, will be highlighted to show the different paths followed by a successful and an unsuccessful concept. The outlook for future VTOL/rotary wing concepts will be evaluated.

12 **Highly Nonplanar Lifting Systems**, Dr. Ilan Kroo, Stanford University

This paper deals with nonplanar wing concepts -- their advantages and possible applications in a variety of aircraft designs. A brief review and assessment of several concepts from winglets to ring wings is followed by a more detailed look at two recent ideas: exploiting nonplanar wakes to reduce induced drag, and applying a "C-wing" design to large commercial transports. Results suggest that potential efficiency gains may be significant, while several non-aerodynamic characteristics are particularly interesting.

13 **The Application of Pneumatic Lift and Control Surface Technology to Advanced Transport Aircraft**, Robert J. Englar, Georgia Tech Research Institute

The application of pneumatic (blown) aerodynamic technology to both the lifting and the control surfaces of advanced transport aircraft can provide revolutionary changes in the performance and operation of these vehicles, ranging in speed regime from Advanced Subsonic Transports to the High Speed Civil Transport, and beyond. This technology, much of it based on the Circulation Control Wing blown concepts, can provide aerodynamic force augmentations of 80 to 100 (i.e., return of 80-100 pounds of force per pound of input momentum from the blowing jet). This can be achieved without use of external mechanical surfaces. Clever application of this technology can provide no-moving-part lifting surfaces (wings/tails) integrated into the control system to greatly simplify aircraft designs while improving their aerodynamic performance. Lift/drag ratio may be pneumatically tailored to fit the current phase of the flight, and takeoff/landing performance can be greatly improved by reducing ground roll distances and liftoff/touchdown speeds. Alternatively, great increases in liftoff weights and payloads are possible, as are great reductions in wing and tail planform size, resulting in optimized cruise wing designs. Furthermore, lift generation independent of angle of attack provides much promise for increased safety of flight in the severe updrafts/downdrafts of microbursts and windshears, which is further augmented by the ability to sustain flight at greatly reduced airspeeds. Load-tailored blown wings can also reduce tip vorticity during high-lift operations and the resulting vortex wake hazards near terminal areas. Reduced noise may also be possible as these jets can be made to operate at low pressures.

The planned presentation will support the above statements through discussions of recent experimental and numerical (CFD) research and development of these advanced blown aerodynamic surfaces, portions of which have been conducted for NASA. Also to be presented will be predicted performance of advanced transports resulting from these devices. Suggestions will be presented for additional innovative high-payoff research leading to further confirmation of these concepts and their application to advanced efficient commercial transport aircraft.

14 **The Future of Very Large Air Transport Vehicles: A Lockheed Martin Perspective**, R. Steven Justice, Anthony P. Hays, and Ed L. Parrott, Lockheed Martin Aeronautical Systems

The Very Large Subsonic Transport (VLST) is a multi-use commercial passenger, commercial cargo, and military airlifter roughly 50% larger than the current Lockheed C-5 and Boeing 747. Due to the large size and cost of the VLST, it is unlikely that the commercial market can support more than one aircraft production line, while declining defense budgets will not support a

dedicated military VLST. A successful VLST must therefore meet airline requirements for more passenger and cargo capacity on congested routes into slot-limited airports and also provide a cost effective heavy airlift capacity to support the overseas deployment of US military forces.

A successful VLST must satisfy three key missions:

- o Commercial passenger service with nominal seating capacity at a minimum of 650 passengers with a range capability of 7,000 to 10,000 miles.
- o Commercial air cargo service for containerized cargo to support global manufacturing of high value added products, 'just-in-time' parts delivery, and the general globalization of trade.
- o Military airlift with adequate capacity to load current weapon systems, with minimal break-down, over global ranges (7,000 to 10,000 miles) required to reach the operational theater without need of overseas bases and midair refueling.

The development of the VLST poses some technical issues specific to large aircraft, but also key technologies applicable to a wide range of subsonic transport aircraft. Key issues and technologies unique to the VLST include: large composite structures; dynamic control of a large, flexible structure; aircraft noise requirements for aircraft over 850,000 pounds; and increased aircraft separation due to increased wake vortex generation.

Other issues, while not unique to the VLST, will critically impact the ability to build an efficient and affordable aircraft include: active control systems; Fly-By-Light/Power-By-Wire (FBL/PBW); high lift systems; flight deck associate systems; laminar flow; emergency egress; and modular design.

The VLST will encounter severe restrictions on weight, ground flotation, span, length, and door height to operate at current airports/bases, gates, and cargo loading systems. One option under consideration is for a sea-based VLST, either a conventional seaplane or Wing-In-Ground effect (WIG) vehicle, which would allow greater operational flexibility, while introducing other design challenges such as water impact loads and salt-water corrosion. Lockheed Martin is currently developing a floatplane version of the C-130 Hercules which will provide experience with a modern sea-based aircraft.

In addition to its own ongoing research activities, Lockheed Martin is also participating in the NASA Advanced Subsonic Technology, High Speed Research (HSR), and other programs which address some of the technologies needed for the VLST. The VLST will require NASA and US aerospace companies to work together to develop new capabilities and technologies for make the VLST a viable part of transportation beyond 2000.

15 Evolution of the Revolutionary Blended-Wing-Body Subsonic Transport, Dr. Robert H. Liebeck, Mark A. Page, and Blaine K. Rawdon, McDonnell Douglas Aerospace

The Blended-Wing-Body (BWB) airplane concept represents a potential revolution in subsonic transport efficiency for Very Large Airplanes (VLA's). NASA is sponsoring an advanced concept study to demonstrate feasibility and begin development of this new class of airplane. In this study, 800 passenger BWB and conventional configuration airplanes have been compared for a 7000 nautical mile design range, where both airplanes are based on technology keyed to 2015 entry into service. The BWB has been found to be superior to the conventional configuration in the following areas: Fuel Burn--31% lower, Takeoff Weight--13% lower, Operating Empty Weight--10% lower, Total Thrust--16% lower, and Lift/Drag--35% higher.

The BWB advantage results from a double deck cabin that extends spanwise providing structural and aerodynamic overlap with the wing. This reduces the total wetted area of the airplane and allows a high aspect ratio to be achieved, since the deep and stiff centerbody provides efficient structural wingspan. Further synergy is realized through buried engines that ingest the wing's boundary layer, and thus reduce effective ram drag. Relaxed static stability allows optimal span loading, and an outboard leading-edge slat is the only high-lift system required.

16 **Large Capacity Oblique All-Wing Transport Aircraft**, Thomas L. Galloway, James Phillips, NASA Ames Research Center; Mark Waters, Elorete Institute; and Robert Kennelly, Jr., NASA Ames Research Center

Dr. R. T. Jones first developed the theory for oblique wing aircraft in 1952, and in subsequent years numerous analytical and experimental projects conducted at NASA Ames and elsewhere have established that the Jones' oblique wing theory is correct. Until the late 1980's all proposed oblique wing configurations were wing/body aircraft with the wing mounted on a pivot. With the emerging requirement for commercial transports with very large payloads, 450-800 passengers, Jones proposed a supersonic oblique flying wing in 1988. For such an aircraft all payload, fuel, and systems are carried within the wing, and the wing is designed with a variable sweep to maintain a fixed subsonic normal Mach number. Engines and vertical tails are mounted on pivots supported from the primary structure of the wing. The oblique flying wing transport has come to be known as the Oblique All-Wing (OAW) transport.

This presentation gives the highlights of the OAW project that was to study the total concept of the OAW as a commercial transport.

17 **A Corporate Supersonic Transport (CST)**, Randall Greene, Aeronautical Systems Corporation and Dr. Richard Seebass, University of Colorado

This talk address the market and technology for a corporate supersonic transport. It describes a candidate configuration. There seems to be a sufficient market for such an aircraft, even if restricted to supersonic operation over water. The candidate configuration's sonic boom overpressure may be small enough to allow overland operation as well.

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Integrated Airframe Technology: The Future of Advanced Composites, David F. Taggart, Lockheed Martin Skunk Works

Advanced composite materials have provided the aerospace community with unprecedented opportunities for design freedom and improved structural performance. While the performance attributes of composites are increasingly being challenged to meet future vehicle requirements, the cost to manufacture composite structures has proved to be the biggest obstacle to their widespread use. Tremendous progress has been made in developing composite materials and related manufacturing technologies, although the design of composite structures that take advantage of these developments, has not followed a parallel evolution. A revolutionary shift in design integration must be implemented for composite materials to provide the affordable performance they have always promised, and which has now become mandatory for the economic viability of future transportation vehicles.

Investigation of a new design paradigm, combined with the recent emergence of specific processing technologies and approaches, can provide a breakthrough in high performance, low cost composite structures, irrespective of quantity produced. This paper will discuss the impetus for exploiting an alternative approach to structural design as a potential solution to affordability, present some aspects of the "Integrated Airframe" design paradigm that is one possible approach to achieving high performance structures at low cost in both prototype and production quantities, and present the status of an ongoing ARPA/Air Force/Skunk Works program that is defining the future of composite airframe design and manufacture.

Fuel Cells for Transportation: Status and Technical/Economic Needs, Glenn Rambach, Lawrence Livermore National Laboratory

More than 150 years after its invention, the fuel cell is showing strong potential for becoming the successor to the internal combustion engine for powering vehicles. While significant progress has been made in the past 30 years in the direction of bringing fuel cells to commercialization, there are some critical barriers in the technology and economics that need to be overcome. Fuel cell stacks have recently been demonstrated as technically viable in small cars, busses, small trucks and in utility applications. This presentation will describe the current state of several fuel cell technologies and show the technical, economic and infrastructure improvements necessary to make them practical, commercial transportation technologies.

Hypersonic Airbreathing Vehicles/Technologies, James L. Hunt, NASA Langley Research Center

Hypersonic airbreathing horizontal takeoff and landing (HTOL) vehicles are highly integrated systems involving many advanced technologies. The design environment is variable rich, intricately networked, and sensitivity intensive; as such, it represents a tremendous challenge. Creating a viable design requires addressing three main elements: (1) an understanding of the "figures of merit" and their relationship, (2) the development of sophisticated configuration discipline prediction methods and a synthesis procedure, and (3) the synergistic integration of advanced technologies across the discipline spectrum. This paper will focus on the vision for hypersonic airbreathing vehicles and the advanced technologies that forge the designs.

The Use of Steady and Pulsed Detonations in Propulsion Systems, Dr. Henry G. Adelman, Thermosciences Institute; Gene P. Menees, NASA Ames Research Center (retired); Dr. Jean-Luc Cambier, Thermosciences Institute; and Jeffrey V. Bowles, NASA Ames Research Center

Detonation wave enhanced supersonic combustors such as the Oblique Detonation Wave Engine (ODWE) are attractive propulsion concepts for hypersonic flight. These engines utilize detonation waves to enhance fuel-air mixing and combustion. The benefits of wave combustion systems include shorter and lighter engines which require less cooling and generate lower internal drag. These features allow air-breathing operation at higher Mach numbers than the diffusive burning scramjet delaying the need for less efficient rocket engine augmentation. A comprehensive vehicle synthesis code has predicted the aerodynamic characteristics and structural size and weight of a typical single-stage-to-orbit vehicle using an ODWE.

Other studies have focused on the use of unsteady or pulsed detonation waves. For low speed applications, pulsed detonation engines (PDE) have advantages in lower weight and higher efficiency than turbojets. At hypersonic speeds, the pulsed detonations can be used in conjunction with a supersonic combustion engine to enhance mixing and provide thrust augmentation.

A Pre-Mixed/Shock-Induced-Combustion Approach to Inlet and Combustor Design for Hypersonic Applications, John P. Weidner, NASA Langley Research Center

High scramjet performance levels are required for successful hypersonic cruise and space launch vehicles. This paper will suggest a higher degree of inlet combustor integration, to accomplish a higher performance level, by injecting fuel within the inlet so that shock waves that terminate at the inlet throat will induce combustion and result in a shorter inlet and combustor design.

Energy Beam Highways Through The Skies, Dr. Leik N. Myrabo, Rensselaer Polytechnic Institute

The emergence of Energy Beam Flight Transportation Systems could dramatically change the way we travel in the 21st Century. A framework for formulating "Highways of Light" and the top level architectures that invoke radically new Space Power Grid infrastructure, are introduced. Basically, such flight systems, hereafter called Lightcraft, would employ off-board energy beam sources (either laser or microwave) to energize on-board dependent "motors" -- instead of the traditional autonomous "engines" with their on-board energy sources (e.g., chemical fuels).

Extreme reductions in vehicle dry mass appear feasible with the use of off-board power and a high degree of on-board artificial intelligence. Such vehicles may no longer need airports for refueling (since they require no propellant), and could possibly pick up travelers at their homes -- before motoring over to one of many local boost stations, for the flight out. With off-board power, hyper-energetic acceleration performance and boost-glide trajectories become feasible. Hypersonic MHD airbreathing propulsion can enable boosts up to twice escape velocity, which will cut trip times to the moon down to 5.5 hours. The predominant technological, environmental and social factors that will result from such transportation systems will be stressed.

This presentation first introduces the remote source siting options for the space power system infrastructure, and then provides three representative laser/microwave Lightcraft options (derived from historical Case Studies): i.e., "Acorn", "Toy Top" and "Disc." Next the gamut of combined-cycle engine options developed for these Lightcraft are examined -- to illuminate the 'emerging technologies' that must be harnessed to produce flight hardware. Needed proof-of-concept experiments are identified, along with the Macro-Level Issues that can springboard these revolutionary concepts into hardware reality.

High Energy Density Matter for Rocket Propulsion, Dr. Patrick G. Carrick, Phillips Laboratory, Edwards AFB

The objective of the High Energy Density Matter (HEDM) program is to identify, develop, and exploit high energy atomic and molecular systems as energy sources for rocket propulsion applications. It is a high risk, high payoff program that incorporates basic and applied research, experimental and theoretical efforts, and science and engineering elements. The HEDM program is co-sponsored by the Air Force Office of Scientific Research (AFOSR) and Phillips Laboratory (PL/RKF) and includes both in-house and contracted University/Industry efforts. Technology developed by the HEDM program offers the opportunity for significant breakthroughs in propulsion systems capabilities over the current state-of-the-art.

One area of great interest is the use of solid cryogenic propellants to increase the density of the propellant and to act as a stable matrix for storage of energetic materials. No cryogenic solid propellant has ever been used in a rocket, and there remain engineering challenges to such a propellant. However, cryogenic solids would enable a wide class of highly energetic materials by providing an environment that is at very low temperatures and is a physical barrier to recombination or energy loss reactions. Previous to our experiments only hydrogen atoms had been shown to be isolated in solid hydrogen. To date we have succeeded in trapping boron, aluminum, lithium, and magnesium atoms in solid hydrogen[1] all of which could result in large performance increases. Small molecules, such as B₂ and LiB, are also of interest.[2] Current efforts involve the search for new energetic small molecules, increasing free radical concentrations up to 5 mole percent, and scale-up of these materials for testing.

The use of cryogenic solid propellants in rocket systems can greatly increase access to space. This technology has the potential to increase payload by as much as a factor of four over current capabilities, allow single-stage-to-orbit options, enable new missions, and provide spin-off benefits in the areas of lasers, explosives and materials.

- References: 1. M. E. Fajardo, S. Tam, T. L. Thompson, and M. E. Cordonnier, Chem. Phys., 189, 351 (1994).
2. C. R. Brazier and Patrick G. Carrick, J. Chem. Phys., 100, 7928 (1994). High Energy Density Materials White Paper

Fusion Power and Propulsion for Future Flight, H. David Froning, Jr., Flight Unlimited

Either of two "clean" and compact fusion power and propulsion systems, that are currently being studied and developed, could revolutionize air and space transportation beyond 2000 if their development is continued and is a success. The talk describes these two promising systems and typical earth-to-orbit and interplanetary flight benefits that they could provide. The talk also describes some commercial applications that these fusion systems are already being used for, together with critical issues that must be resolved before they can be used for future flight.

Advanced Space Propulsion, Dr. Robert H. Frisbee, Jet Propulsion Laboratory

This presentation describes a number of advanced space propulsion technologies with the potential for meeting the need for dramatic reductions in the cost of access to space, and the need for new propulsion capabilities to enable bold new space exploration (and, ultimately, space exploitation) missions of the 21st century. For example, current Earth-to-orbit (e.g., low Earth orbit, LEO) launch costs are extremely high (ca. \$10,000/kg); a factor 25 reduction (to ca. \$400/kg) will be needed to produce the dramatic increases in space activities in both the

civilian and government sectors identified in the Commercial Space Transportation Study (CSTS). Similarly, in the area of space exploration, all of the relatively “easy” missions (e.g., robotic flybys, inner solar system orbiters and landers; and piloted short-duration Lunar missions) have been done. Ambitious missions of the next century (e.g., robotic outer- planet orbiters/probes, landers, rovers, sample returns; and piloted long- duration Lunar and Mars missions) will require major improvements in propulsion capability. In some cases, advanced propulsion can enable a mission by making it faster or more affordable, and in some cases, by directly enabling the mission (e.g., interstellar missions).

As a general rule, advanced propulsion systems are attractive because of their low operating costs (e.g., higher specific impulse, Isp) and typically show the most benefit for relatively “big” missions (i.e., missions with large payloads or V, or a large overall mission model). In part, this is due to the intrinsic size of the advanced systems as compared to state-of-the-art (SOTA) chemical propulsion systems. Also, advanced systems often have a large “infrastructure” cost, either in the form of initial R&D costs or in facilities hardware costs (e.g., laser or microwave transmission ground stations for beamed energy propulsion). These costs must then be amortized over a large mission to be cost-competitive with a SOTA system with a low initial development and infrastructure cost and a high operating cost. Note however that this has resulted in a “Catch 22” standoff between the need for large initial investment that is amortized over many launches to reduce costs, and the limited number of launches possible at today’s launch costs.

Some examples of missions enabled (either in cost or capability) by advanced propulsion include long-life station-keeping or micro-spacecraft applications using electric propulsion or BMDO-derived micro-thrusters, low-cost orbit raising (LEO to GEO or Lunar orbit) using electric propulsion, robotic planetary missions using aerobraking or electric propulsion, piloted Mars missions using aerobraking and/or propellant production from Martian resources, very fast (100- day round-trip) piloted Mars missions using fission or fusion propulsion, and, finally, interstellar missions using fusion, antimatter, or beamed energy.

The NASA Advanced Propulsion Technology program at the Jet Propulsion Laboratory (JPL) is aimed at assessing the feasibility of a range of near-term to far-term advanced propulsion technologies that have the potential to reduce costs and/or enable future space activities. The program includes cooperative modeling and research activities between JPL and various universities and industry; and directly-supported independent research at universities and industry. The cooperative program consists of mission studies, research and development of ion engine technology using C60 (Buckminsterfullerene) propellant, and research and development of lithium-propellant Lorentz-force accelerator (LFA) engine technology. The university/ industry-supported research includes modeling and proof-of-concept experiments in advanced, high-Isp, long- life electric propulsion, and in fusion propulsion.

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Presentation Hardcopies

Session 1:

Historical Background and General Future Perspective

The History of Transportation, With a Peek Into the Future 3

Dr. John D. Anderson, Jr.

In Search of Cybernautics 59

Prof. Steven C. Crow

The New Organization: Rethinking Work in the Age of Virtuosity 83

Duncan B. Sutherland

THE HISTORY OF TRANSPORTATION, WITH A PEAK INTO THE FUTURE

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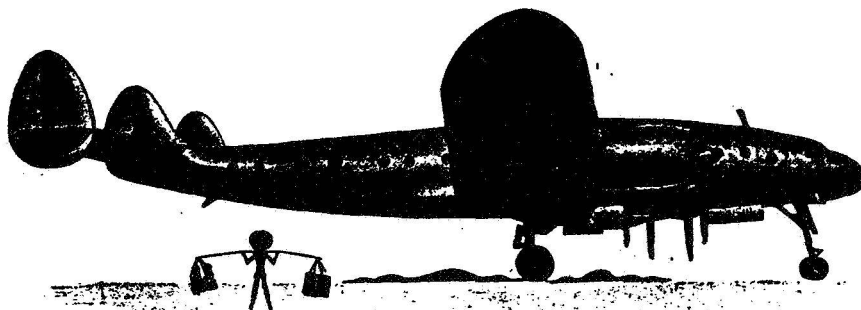
PREAMBLE

(EDITORIAL)



PAYLOAD IS PEOPLE OR PACKAGES

A MOST CURSORY study of the Constellation's performance record indicates immediately that it can never be considered a one-job transport. *Versatility* is the word. Interiorwise, for instance, the Constellation is easily adapted to meet the commercial demand of the specific route, to carry its payload in terms of people or packages or both. Flightwise, it is able to operate most economically over the distance required—whether transcontinentally or on flights as short as 100 miles. Indeed, versatility is the word. Overland express, sleeper or inter-city local, the Constellation is designed to solve *special* problems of the individual airline.



The Constellation

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FOR NEW WORLD STANDARDS IN AIR TRANSPORTATION
LOOK TO *Lockheed* FOR LEADERSHIP

Lockheed Aircraft Corporation, Burbank, California



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Yes, just imagine an airline equipped with 20 huge Mars flying boats like those now being built for the U. S. Navy! World's largest planes, they weigh 82 tons, ten tons more than the original Mars. World's safest overocean aircraft, they can take off or land at sea. World's most efficient planes, they will operate at the unbelievably low cost of 10 cents per ton mile!

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No untried, visionary design, the Mars' type has been tested and proven in grueling wartime service with the Navy. Victory will find Mars production lines fully manned and tooled to assure prompt delivery and minimum production costs. No wonder Martin Mars transports are known as, "the answer to an airline's prayer!"

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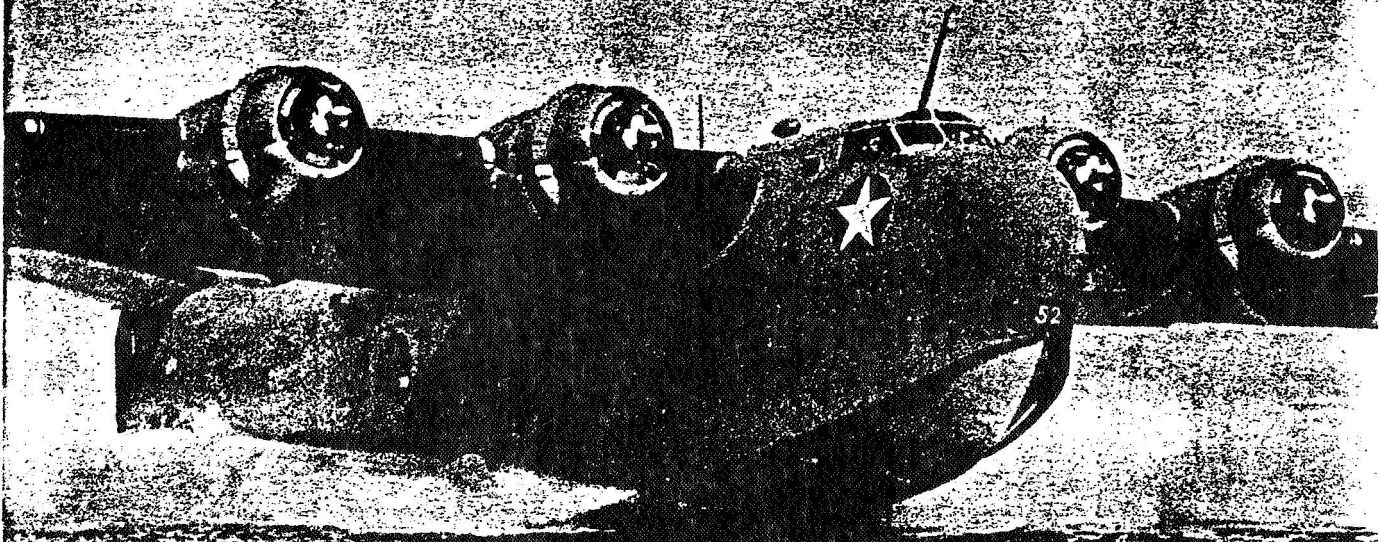
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Just How Big Are The New Mars Transports?

- If stood on one wing, the Mars' other wingtip would tower 200 feet into the air . . . as high as a 20-story building.
- Mars' wings are so thick that crew members can enter them to service engines while in flight.
- These Mars transports each have a cubic content equivalent to a 14 to 16 room mansion.
- Each Mars contains 1½ million rivets—4¾ miles of wiring—¾ of a mile of piping—18 inter-plane phones.
- When fully fueled, these ships carry a tank-car of gasoline for their 4 huge engines.

TOMORROW'S USE OF TODAY'S PLANES



By L. Welch Pogue, CHAIRMAN CIVIL AERONAUTICS BOARD

(L. Welch Pogue's article is the fourth in a series by aviation's top-flight executives. While Air Trails is designed for presenting the more popular aspects of current aviation, thinking readers have expressed interest in matters of moment within the industry. To fill this demand, future lead articles will continue authoritative discussions of topics of paramount importance to your industry.—Editor.)

HOW long will the war continue? How many and what types of surplus aircraft will we have on hand when peace comes? How many war-veteran transports can be used efficiently by our airlines, and how many should we make available to foreign lines? How soon can aircraft manufacturers produce new and more modern types of transport planes? What may be the international arrangements for controlling and regulating international air traffic, and what volume of traffic will be permitted?

Answers to these and many other important questions must be found before we can dispose intelligently of the many-thousand aircraft the United States government will own on the day hostilities cease.

During the war our transport routes have expanded greatly. Under the direction of our armed forces we are operating 150,000 miles of routes. Those planes carry everything from medical supplies to munitions, and provide fast communication all over the world. In addition, our commercial carriers operate some 110,000 miles of regular routes with drastically curtailed fleets.

We have generated a tremendous machinery for air war. With the coming of peace, a great many of these aircraft will lose immediately much of their value. It is very well to say, "Convert them

to other uses." But which types of planes and to what uses? The very possession of the vast fleet of bombers and fighters and cargo carriers would prove as great a problem as its lack proved to be when war came.

It is obvious, then, that we must plan for the wisest possible disposition of these planes. Unless our best minds reach sound conclusions with respect to the problem, American progress in air transportation and aircraft development could be arrested for a decade.

No group of individuals, no group of trade associations and councils, no private enterprise whatsoever can cope with the problem successfully. The Federal government alone can hope to take effective action, for the compelling reason that the government will own the tens of thousands of airplanes which will create the problem.

We could, of course, simply make no plans. At the end of the war we could auction the planes to the highest bidders. Were we to take this sort of action, we may be reasonably sure we will have wasted a vast and costly defense reserve, glutted the transport market for years to come and, even more serious, struck a blow at the capacity of the industry to manufacture and develop airplanes from which it could not recover for years.

Such a course not only would hamstring commercial development; it shortly would lay waste to our aerial defenses—a situation of which an alert enemy might readily take sudden advantage.

True, we would possess a military airfleet second to that of no other nation. This would provide insurance against attack, but for only a comparatively short time. Our reserves would become static. We cannot afford to depend upon fixed and unchanging structures, for no instrument of war or peace becomes obsolete so fast as an

AIR TRAILS

Pictorial

A STREET AND SMITH PUBLICATION

WINGED WORLD

THEODORE ROOSEVELT once said something that could very well be applied today. We forget the exact words, but, in effect, it was "Anyone can make a mistake once. Only a fool makes the same mistake twice." America made her mistakes before this war. Typical was our decision not to fully fortify Guam because it would provoke the Japanese. The next time Guam will be properly fortified. We won't repeat our other errors, either. In aviation, too, there were some slips, due mostly to an intangible something about our outlook; whether it was indifference to what was going on in the world, or lack of imagination, or something else, it is impossible to say. We were looking at the trees instead of the woods.

Regardless, we have done marvelously well with the war. We have fine equipment, much of it better than anything comparable in the world, and more of it than all the other air forces of the earth put together. Yes, we can be justly proud of our record in this war. Yet, today, we still make some late starts in experimental aviation. One was the gas turbine and jet propulsion. When, at the time of the Battle of Britain, Italy successfully flew her jet-propelled Caproni-Campini, most of us who should have known better laughed it off as a fraud and the flight photographs as clever trickery. (To keep the record straight Britain's Captain Whittle was then well along with his own experiments.) More recently, Germany has used rocket-propelled fighters, and her Vengeance weapons are admittedly the beginning of a revolutionary trend in warfare the future limits of which no man can pretend to see. The fact that she does these things in desperation should not be an excuse for lack of contemporary pioneering. Now there is a reason why we were not first with jet propulsion. We knew what was cooking. We looked into the matter. But we decided again and again that in the light of the then foreseeable future, such radical proposals were impractical. There we erred, for the future is always soon upon us. It is not that we can't do it. Rather it is that we are too conservative, or too practical in a business-like way, too ready to scorn other people's radical attempts. The truth is that we cannot afford to take chances with our future by not delving into every aspect of every avenue of every possible future aeronautical development.

Research is a guarantee of future existence. For research there must be funds to keep places like the National Advisory Committee for Aeronautics and the Army's Wright Field tooled up with men and equipment to do the job. But just as much, it requires that YOU, you who are in aviation, you who hope to get into aviation, be imaginative in your outlook. Be alert for the faint beginnings of a trend; make a trend your life work, whether it be the perfection of flying wings, turbines, rocket engines, or pushbutton airplanes. But don't let them turn you into a standard AN5 nut and bolt!

FEBRUARY, 1945—VOLUME XXIII, NO. 5

CONTENTS

THEY FLY TAIL FIRST	By Edward Yulke	23
"BUSH FLYING" IS DEAD	By Keith Petrich	26
THE FIGHTER CONTROLLER	By Capt. David Harbour	28
"MARAUDE" MAGRUDER	By Leonard Engel	30
THE HELICOPTER'S FUTURE	By Col. H. F. Gregory	31
CBI THUNDERBOLT		32
AIR TRAILS PLANBOOK		35
YOUR JOB IN AVIATION, Part III	By Gene Kropf	36
AIR PROGRESS	By Douglas Rolfe	38
MODEL MATTERS	By Edward Yulke	
Dope Can		40
Club Chatter		41
TAILLESS TRAINER	By H. A. Thomas	42
THE NAVY GAS MODEL DIRIGIBLE	By Ted Alexander	44
G.I. DOODLES		46
WOG	By William Winter	47
LOCKHEED LINER	By William P. Moss	50
HAWKER TEMPEST		51
AERONCA ARROW AND TRAINER IN COLOR		52
FOOD FOR GUNS		95
STRATEGIC MOSQUITO		96
DEPARTMENTS		
Meet The Authors		8
25 Years This Month		10
Aviation Tomorrow	By John Fomey Rudy	13
What's Your Idea?	By Edward Yulke	54
COVER PHOTO IN FULL COLOR—COURTESY BELL AIR-CRAFT CORP.		

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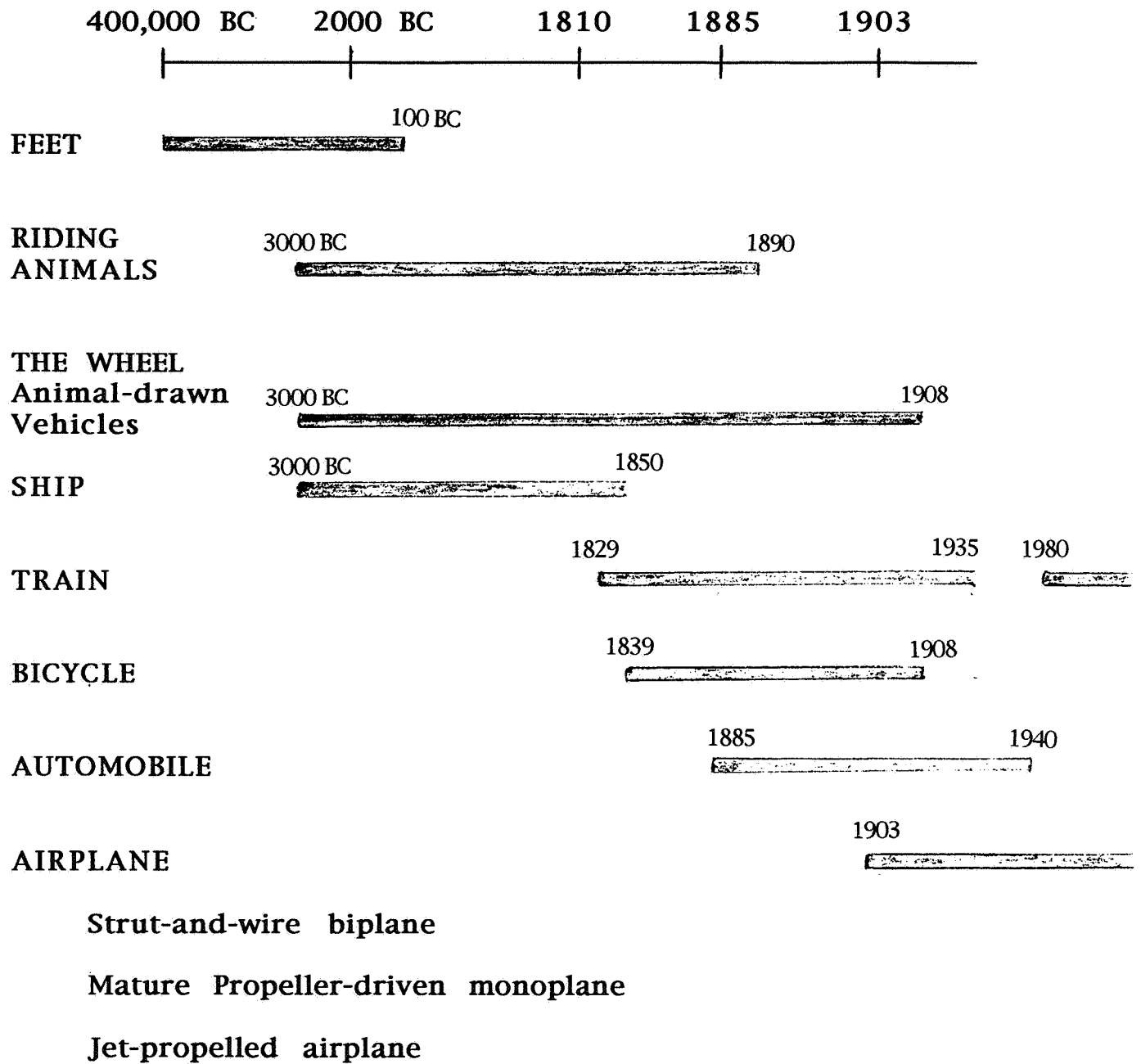
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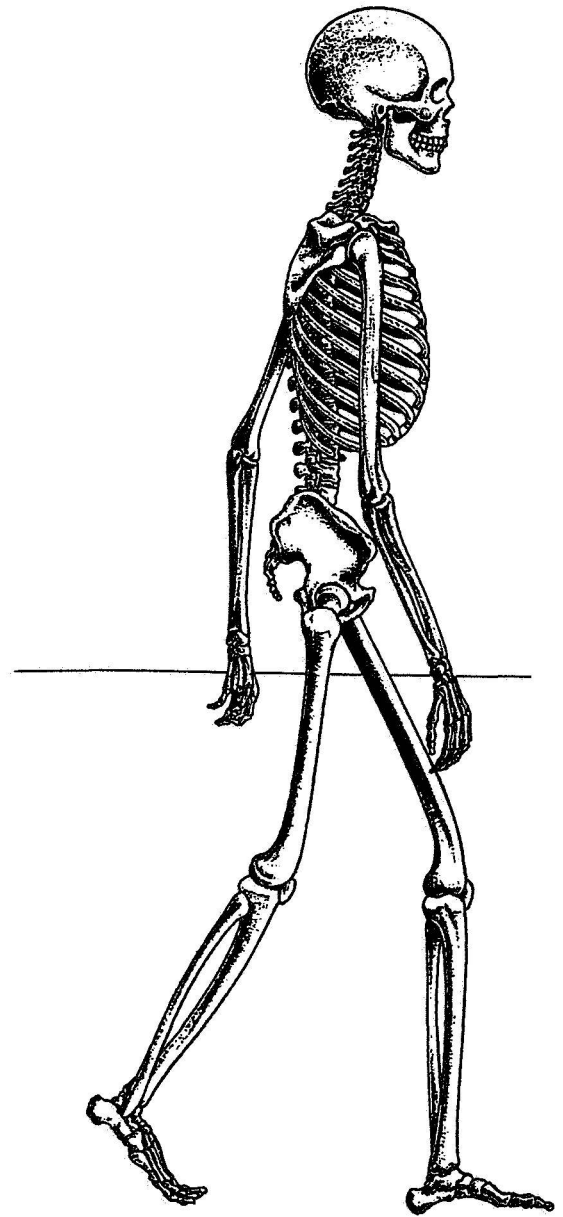
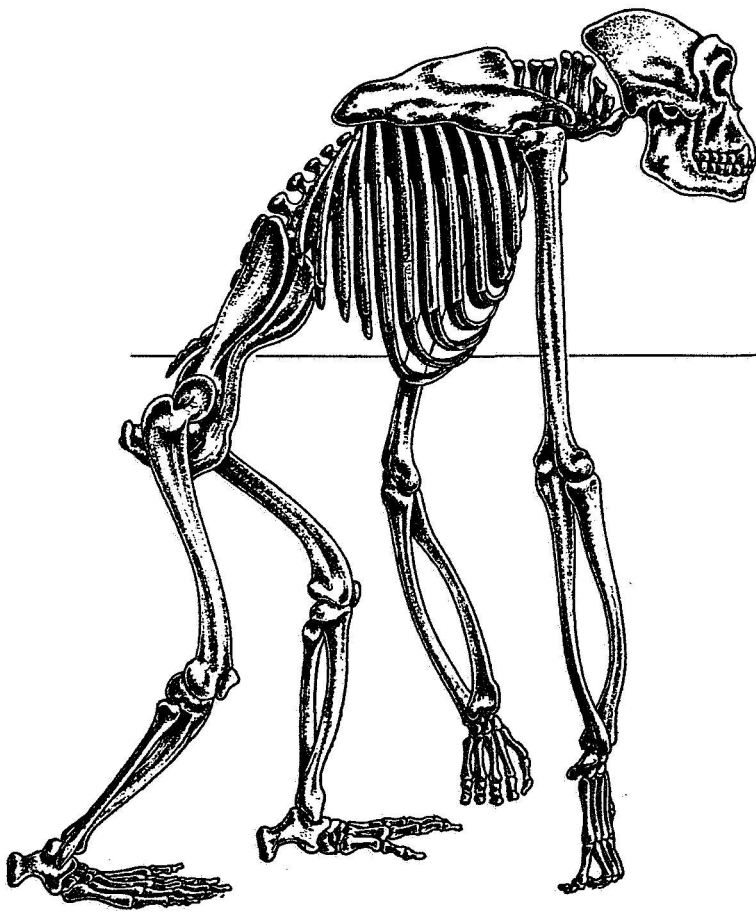
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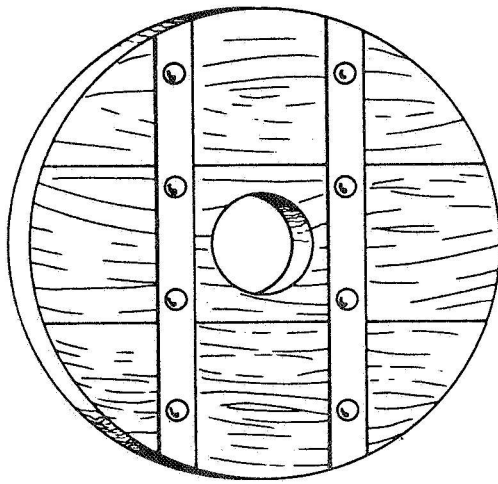
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HEYDAYS OF MODES OF TRANSPORTATION







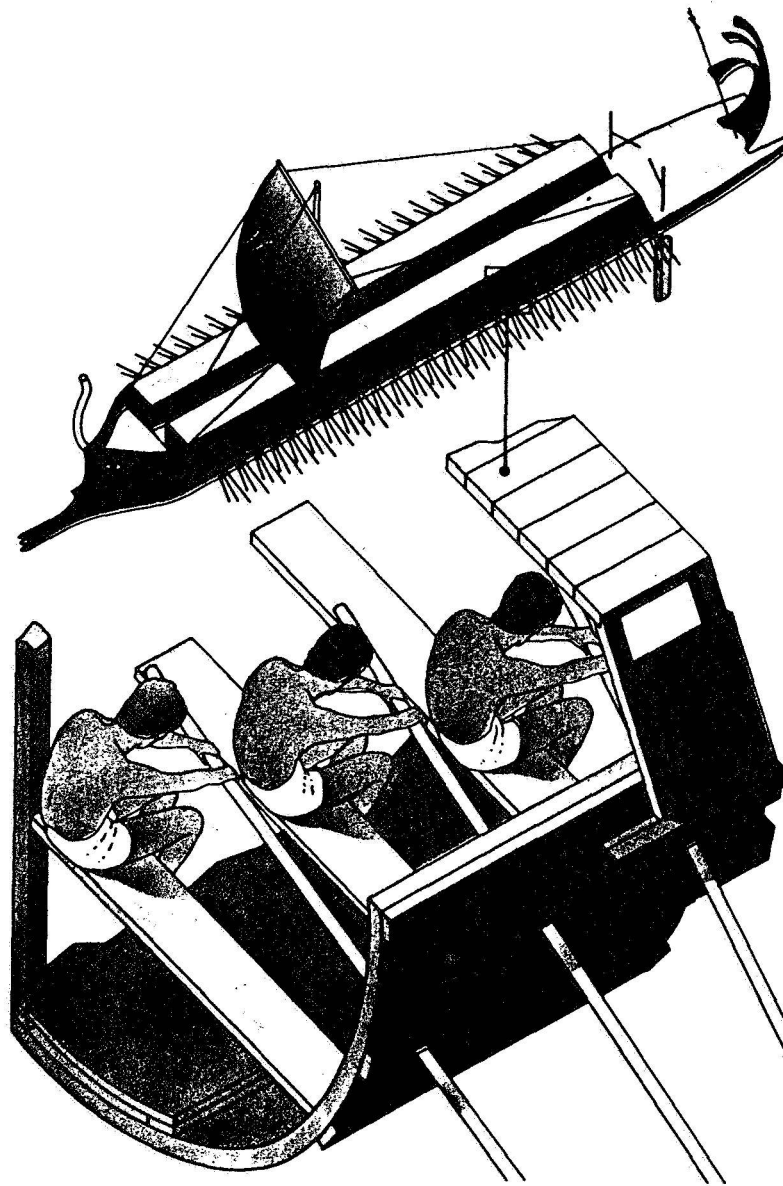


Wheel fashioned from wooden planks held together with metal clamps



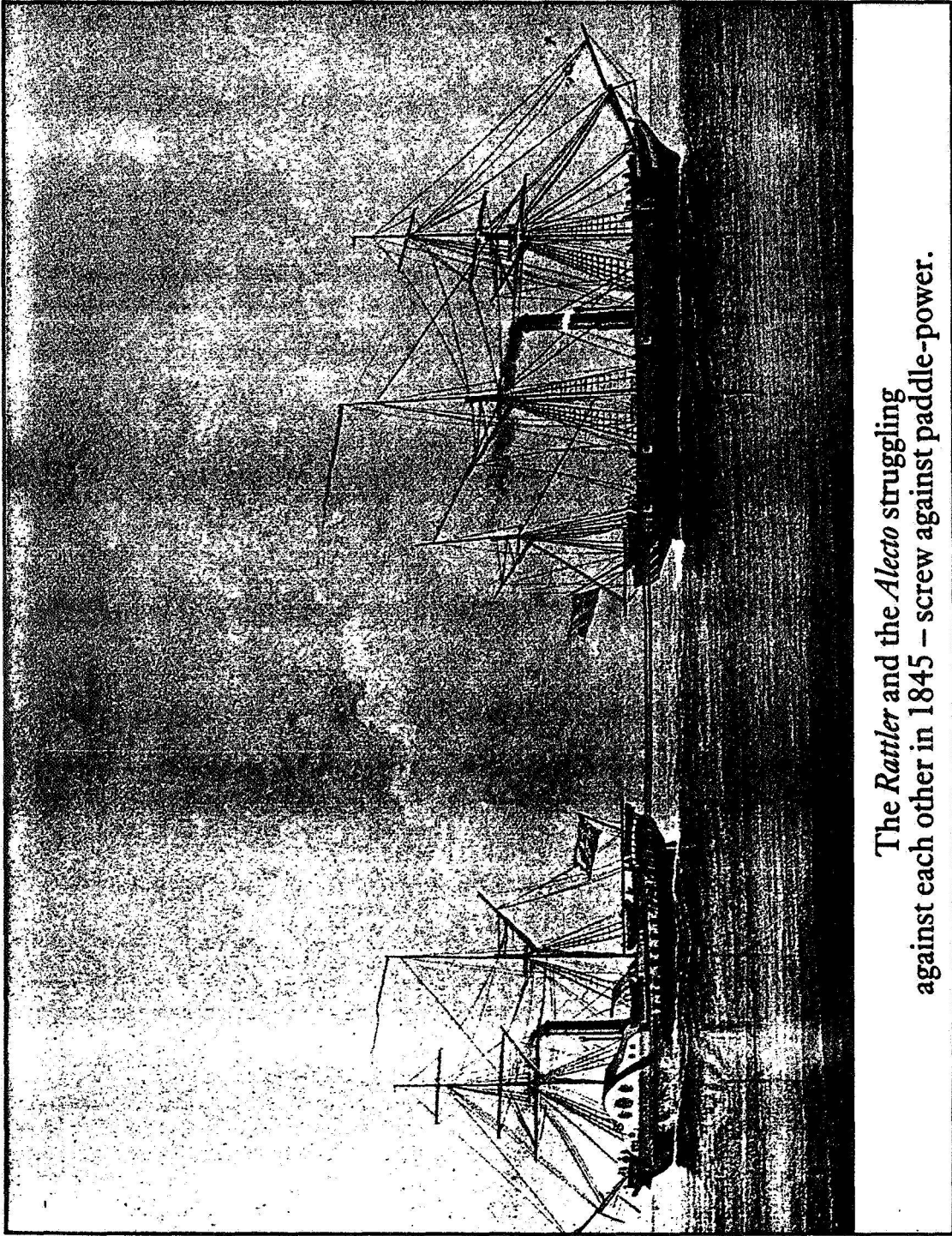


Dugout Canoe (Bronze Age)

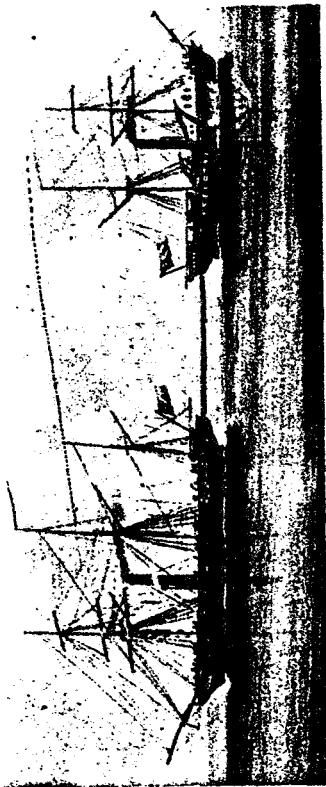


A Greek trireme of about 500 BC. There were three banks of oars pulled by 180 rowers, probably

one to an oar. Sails supplemented the oars, except during battle. Note the powerful ram.

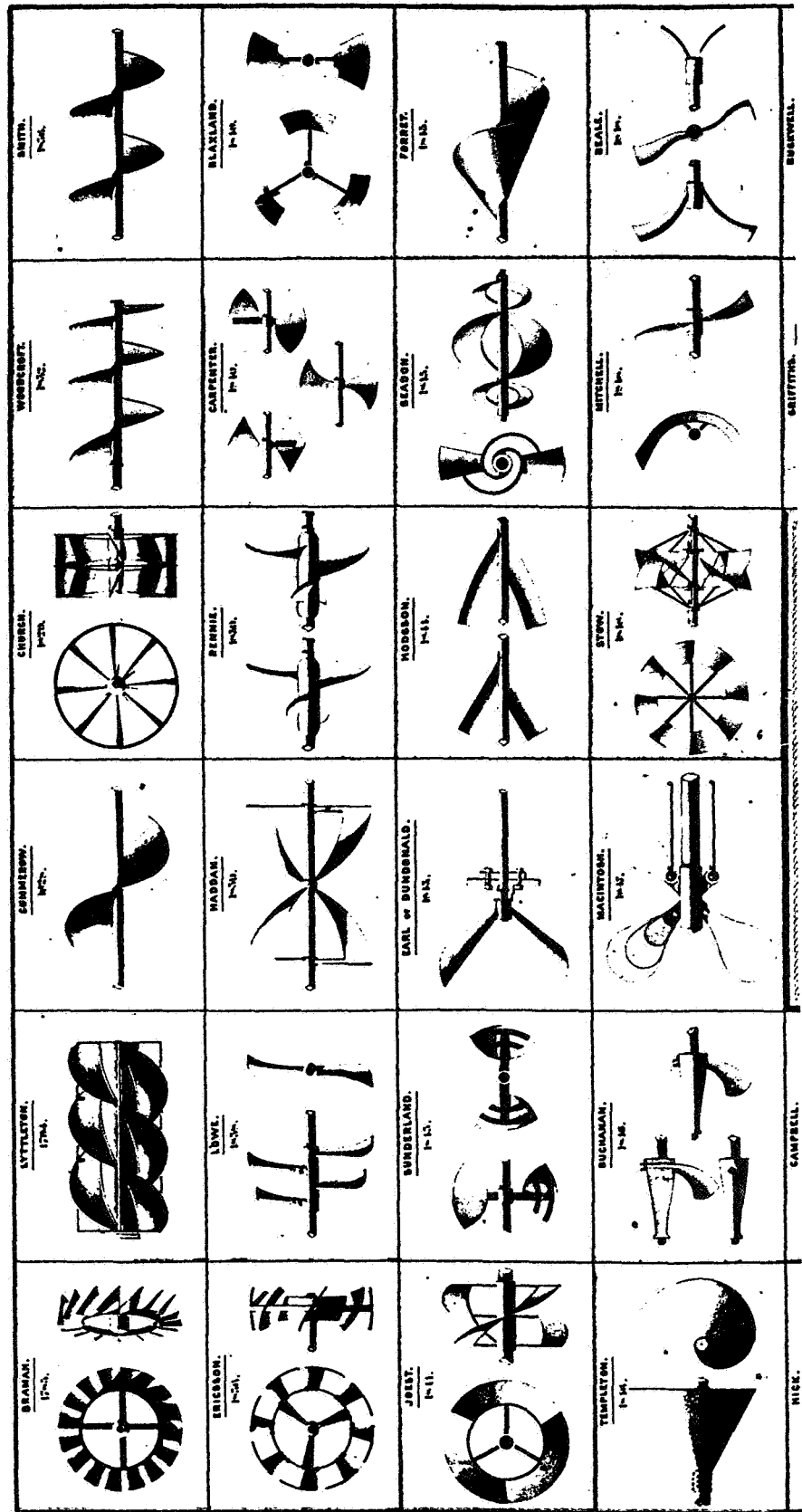


The *Rattler* and the *Alecto* struggling
against each other in 1845 – screw against paddle-power.



The superiority of the screw for marine propulsion was convincingly demonstrated in 1845 in a contest (left) between the warships *Rattler* (propeller) and

Alceto (paddle-wheels). By that time screw propulsion had been tested for more than half a century, using a great variety of designs (below).



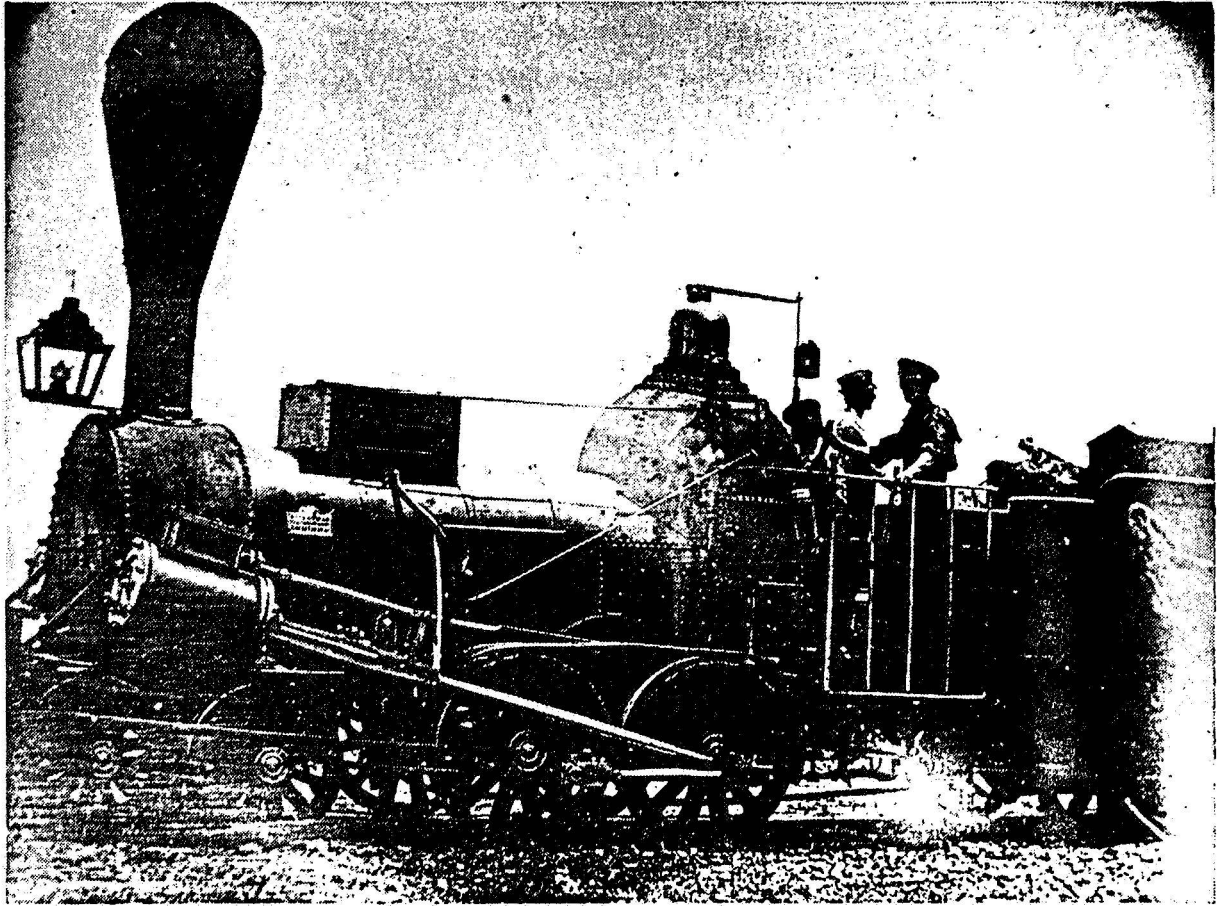


Figure 12.1 Early locomotive of American type, New London and Northern Railroad, 1843 (Courtesy New London Historical Society)

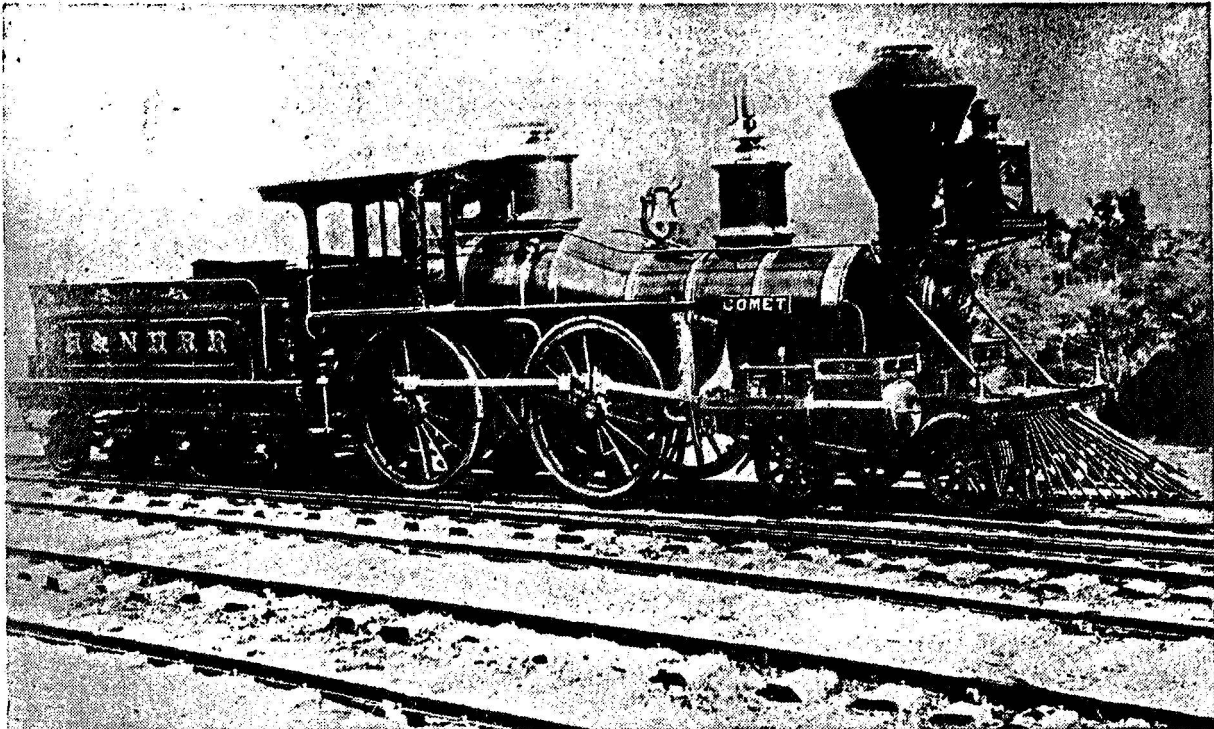


Figure 12.2 Coal-burning passenger locomotive, 1864

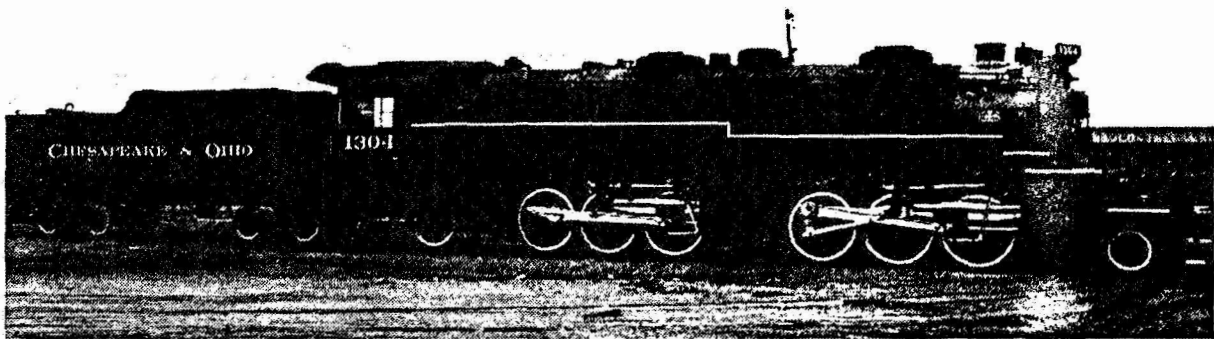


Figure 12.7 Last main-line steam locomotive built by the Baldwin Locomotive Works for use in the United States (Courtesy Chesapeake and Ohio Railway)

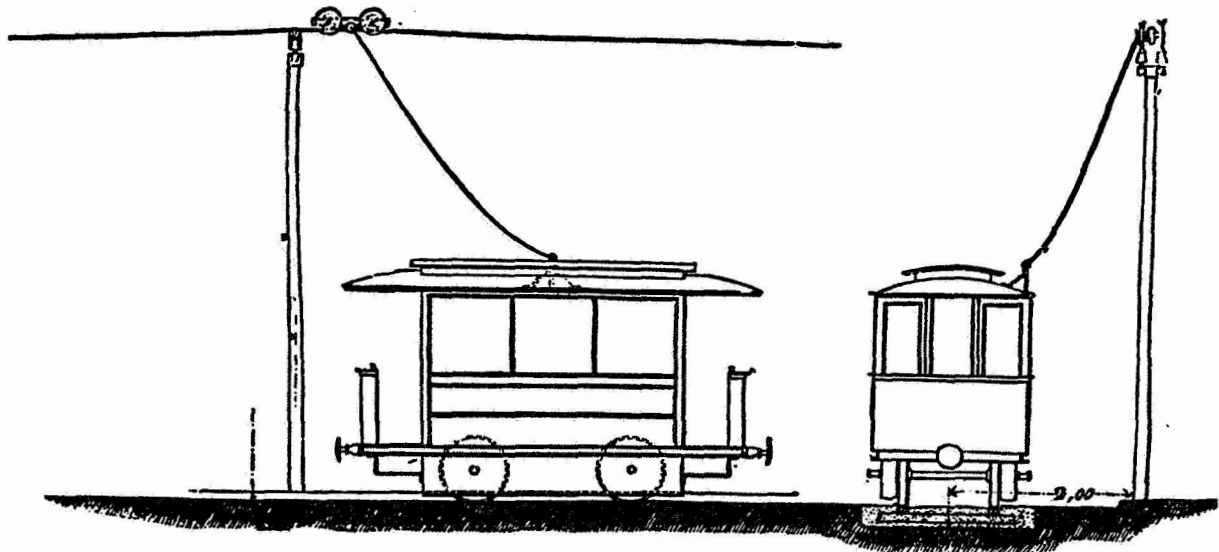


Figure 12.11 Electric street railway in Lichterfelde near Berlin (From *Die Eisenbahn*, 1881)

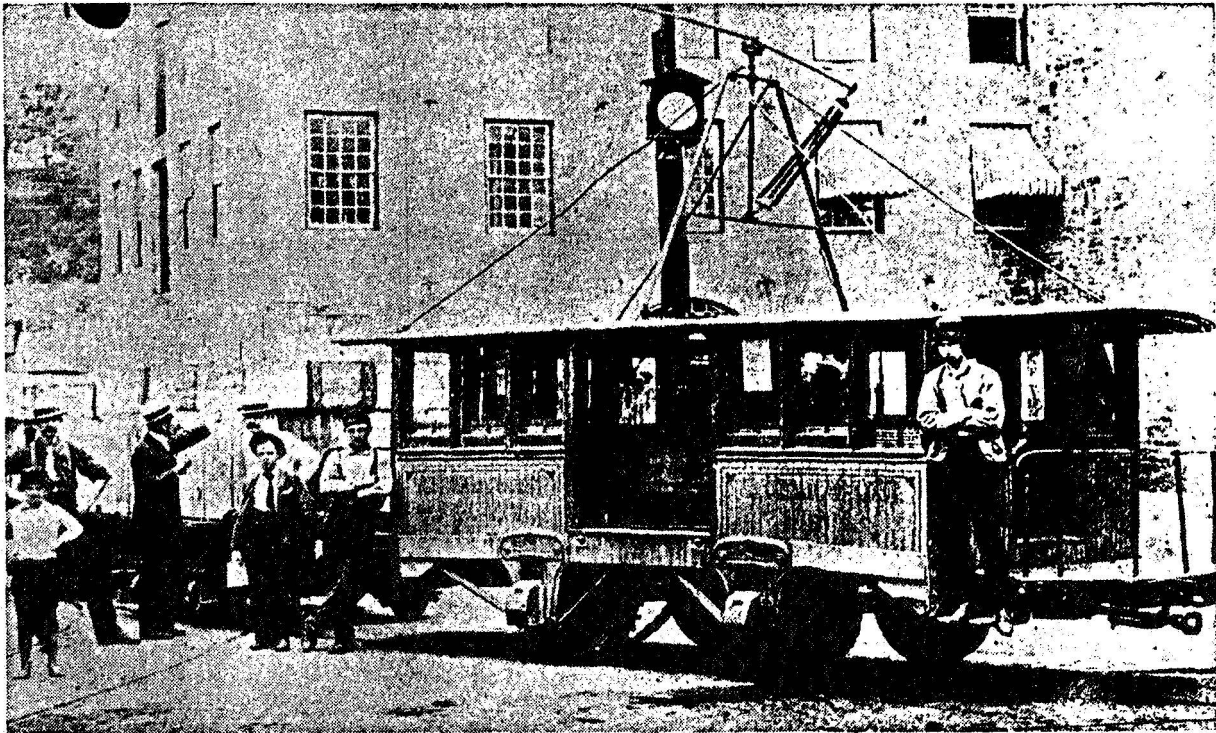


Figure 12.3 First American electric freight locomotive, Ansonia, Connecticut
(Courtesy Charles Rufus Harte)

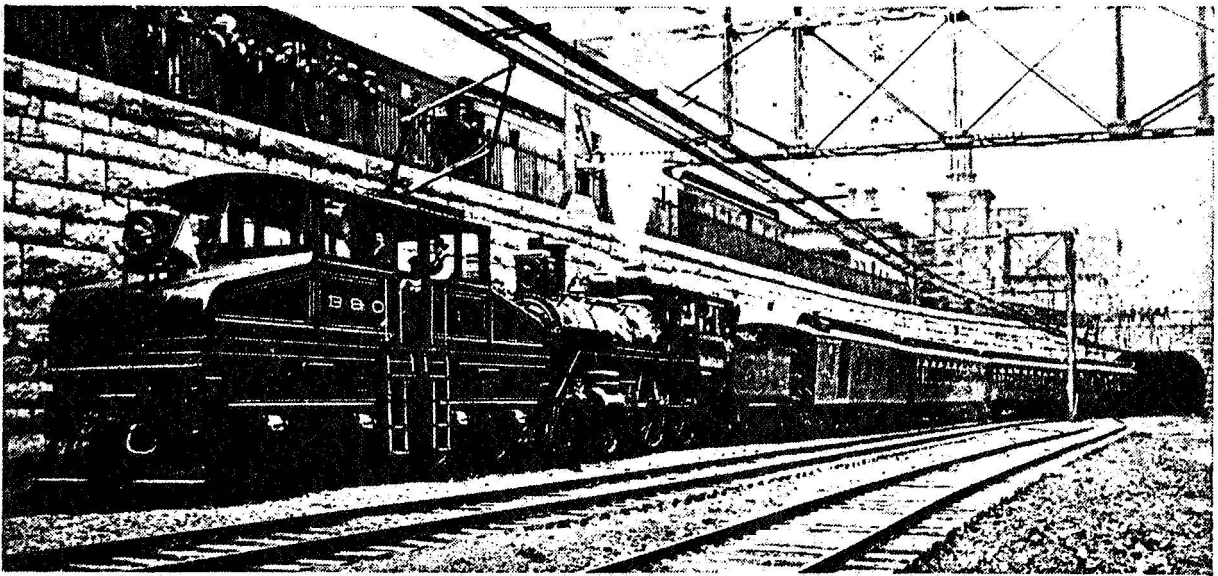
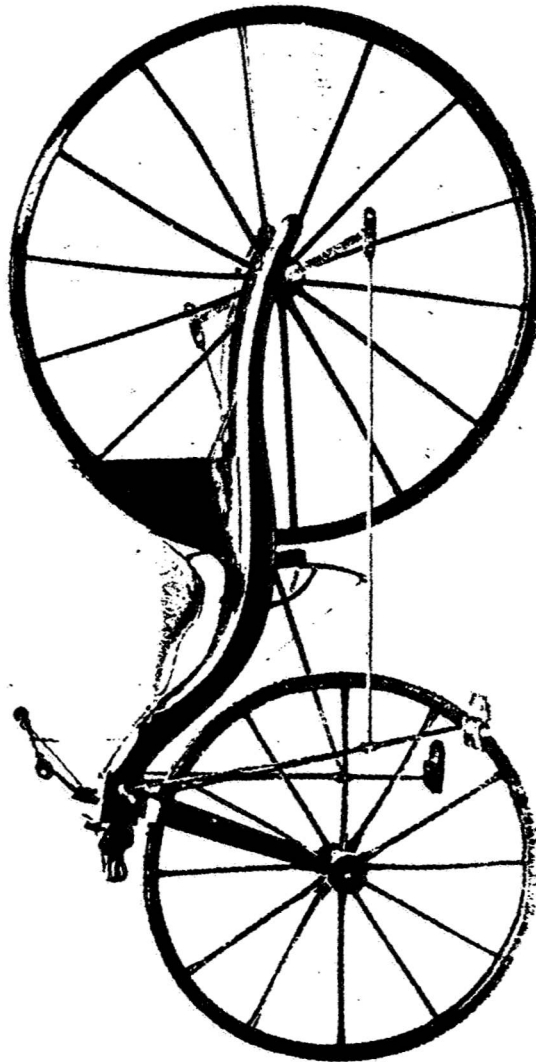
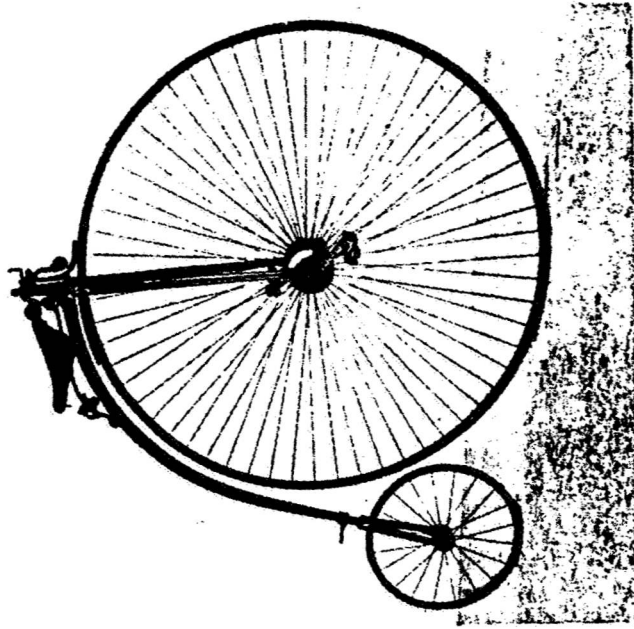


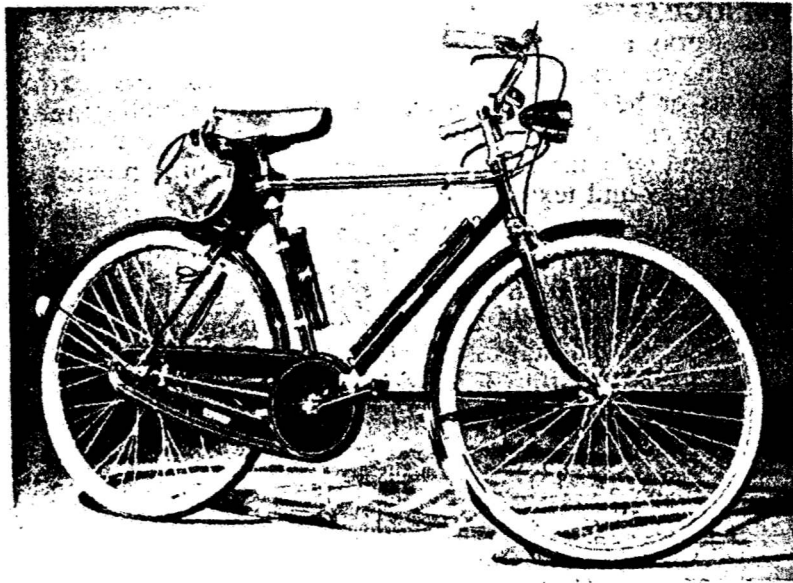
Figure 12.5 Electric locomotive pulling Baltimore and Ohio train, 1895
(Courtesy General Electric Co.)

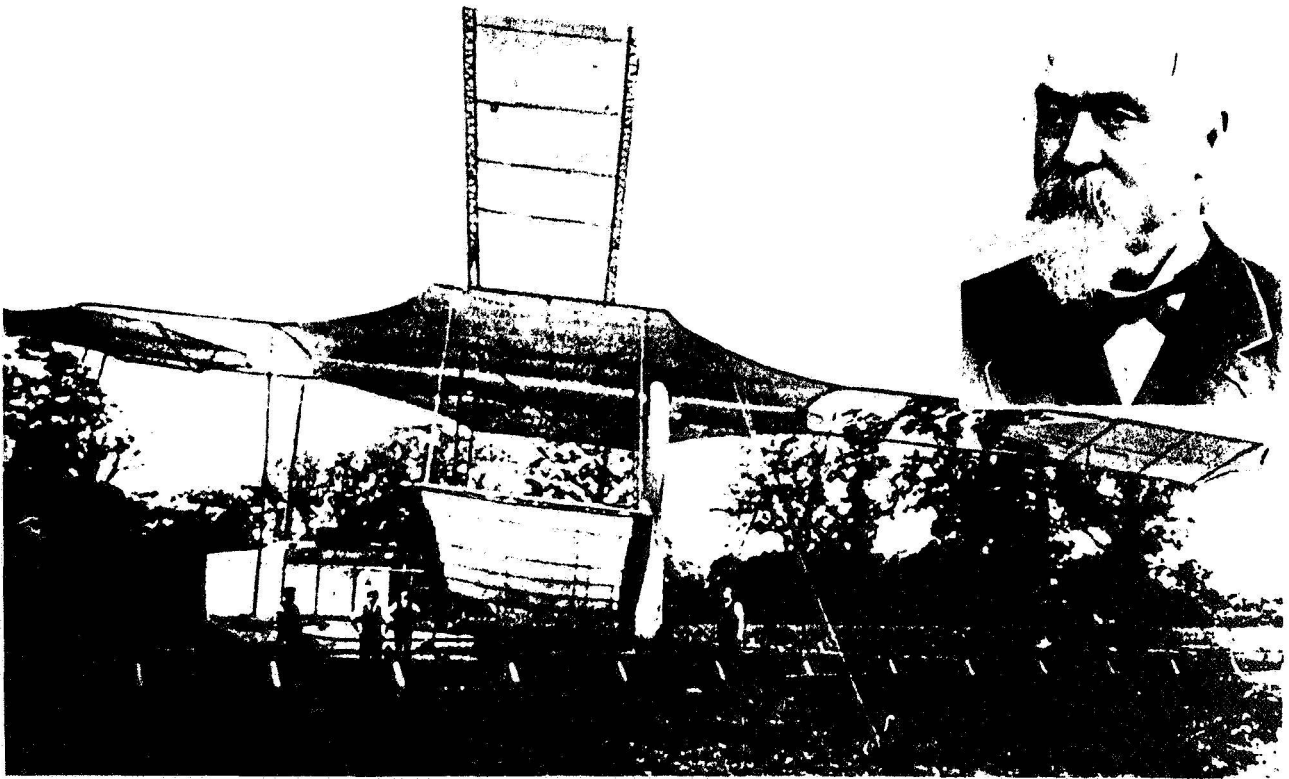
Figure 12.8
Diesel-electric locomotive
(Courtesy New York,
New Haven and Hart-
ford Railroad)





(Left) Macmillan's Hobbyhorse, c. 1839. (Right) Ordinary bicycle, 1883.





Hiram Maxim

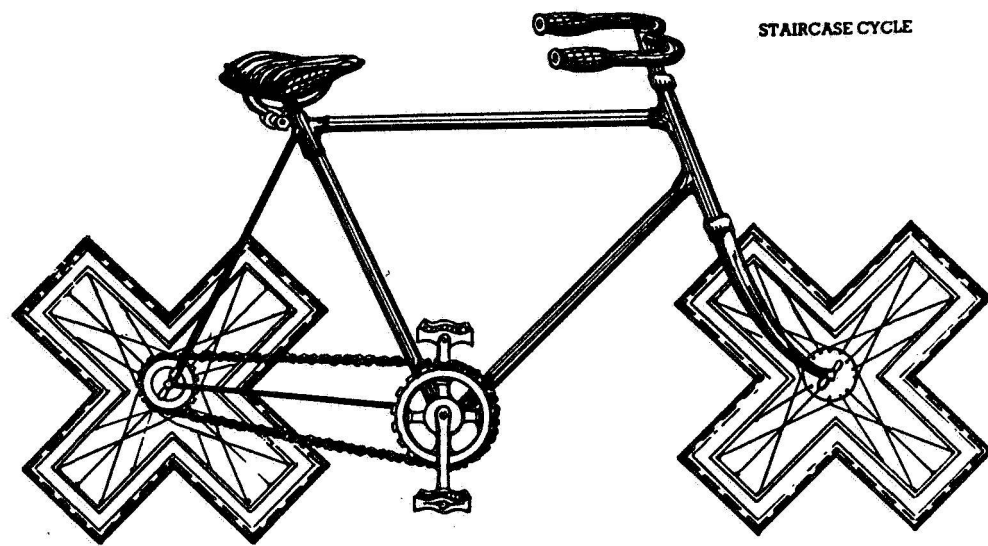


Figure III.5. A bicycle adapted for stairs. One of the many ordinary objects that have been “improved” for the modern consumer by Jacques Carelman and illustrated in his *Catalogue of unfindable objects*. The catalog contains “improvements” to various items, including plumbing fixtures, furniture, household goods, and sports equipment. Source: Jacques Carelman, *A catalogue of unfindable objects* (London, 1984), p. 56.

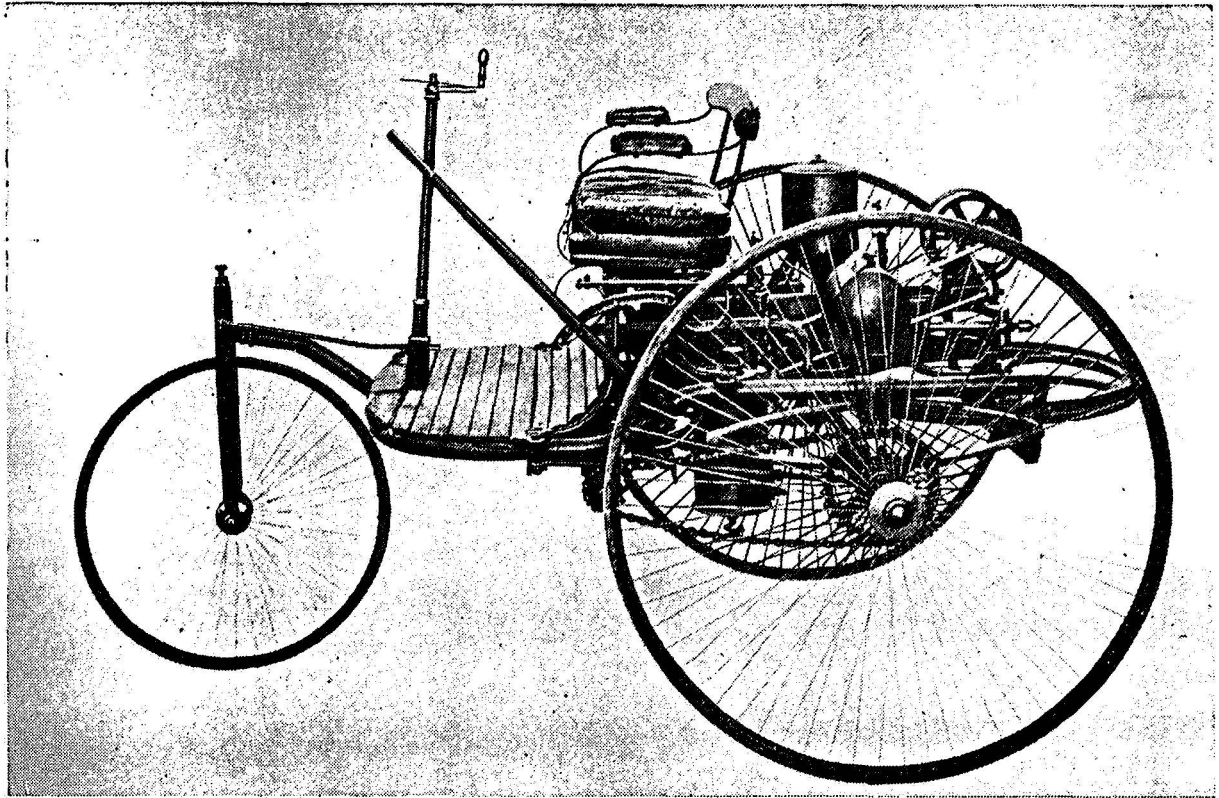
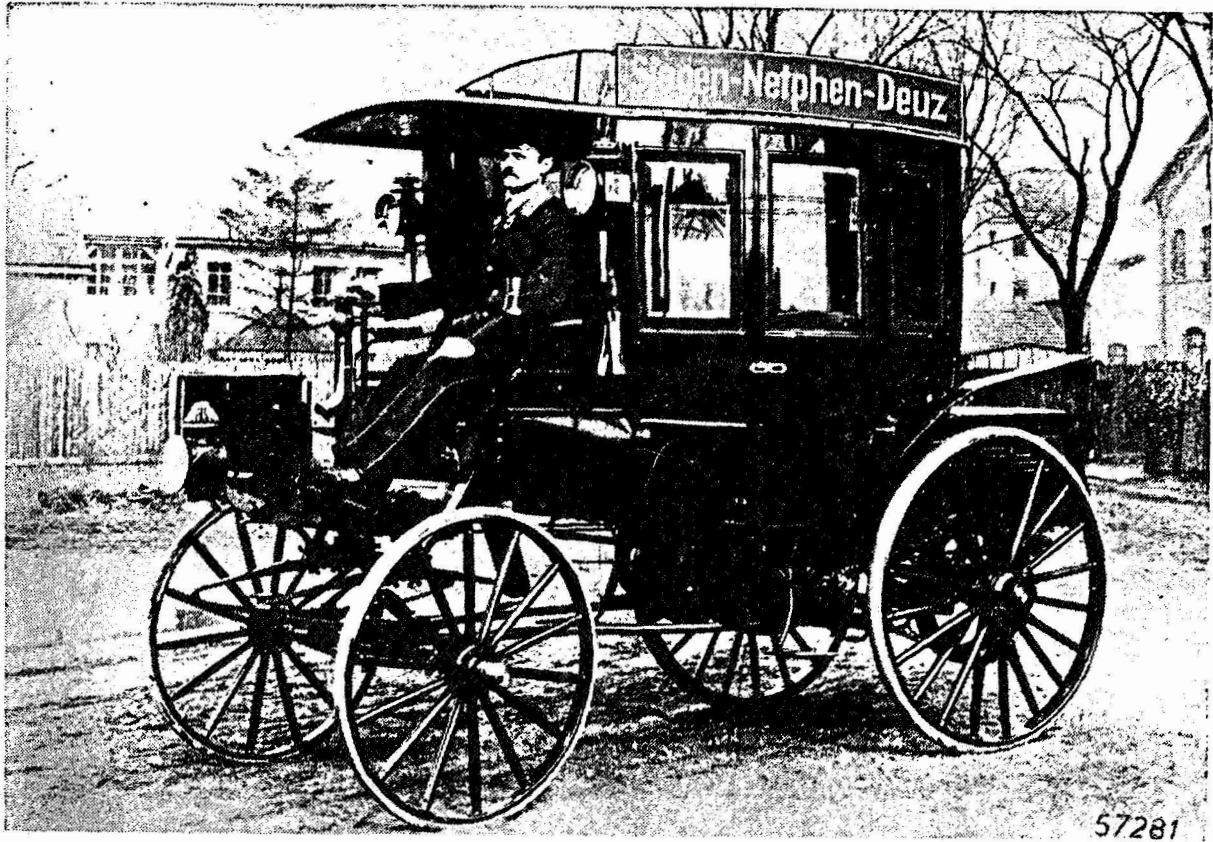
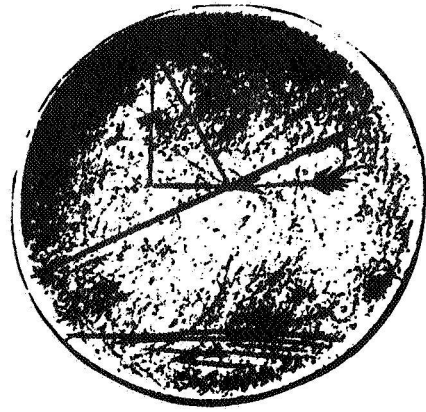
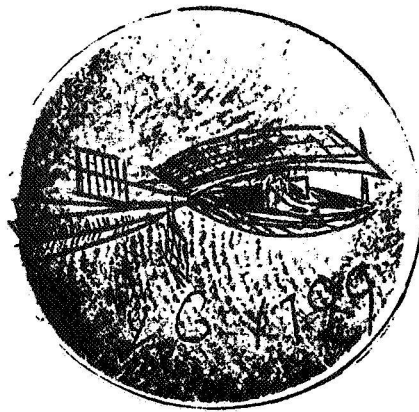


Figure 12.13 First automobile—Benz, 1885 (Courtesy Daimler-Benz Aktiengesellschaft)



57281

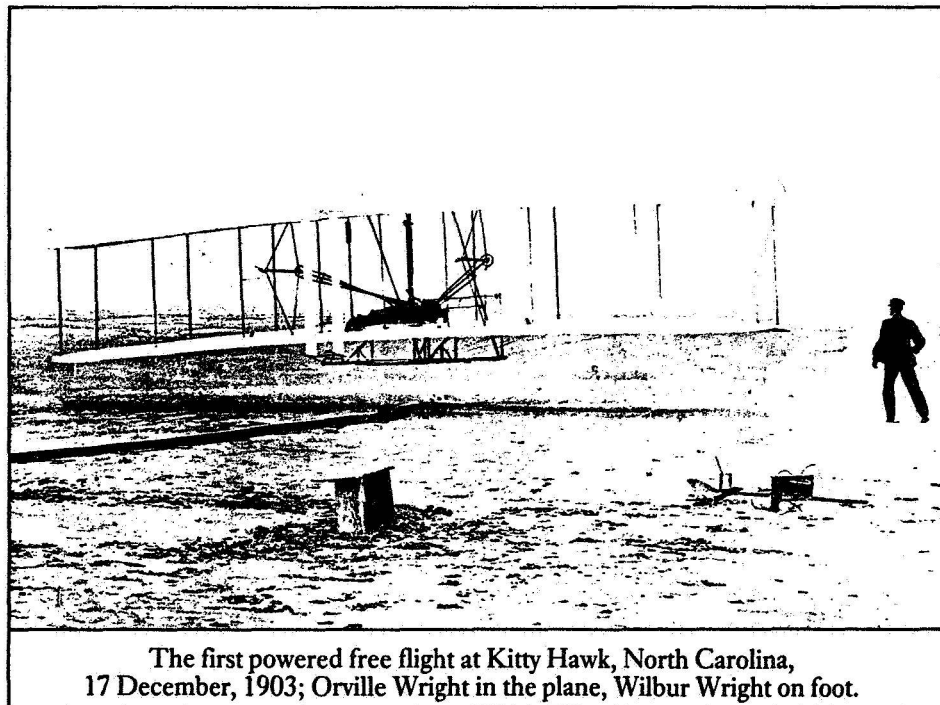
Figure 12.14 First motorbus—Benz, 1895 (Courtesy Daimler-Benz Aktiengesellschaft)



George Cayley



Otto Lilienthal in
one of his gliders, 1896.



The first powered free flight at Kitty Hawk, North Carolina,
17 December, 1903; Orville Wright in the plane, Wilbur Wright on foot.

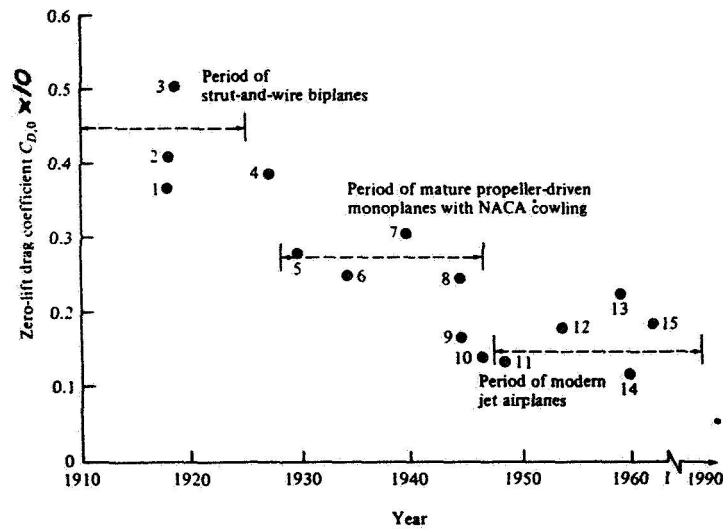


Figure 6.60 Use of zero-lift drag coefficient to illustrate three general periods of twentieth-century airplane design. The numbered data points correspond to the following aircraft: (1) SPAD XIII, (2) Fokker D-VII, (3) Curtiss JN-4H Jenny, (4) Ryan NYP (*Spirit of St. Louis*), (5) Lockheed Vega, (6) Douglas DC-3, (7) Boeing B-17, (8) Boeing B-29, (9) North American P-51, (10) Lockheed P-80, (11) North American F-86, (12) Lockheed F-104, (13) McDonnell F-4E, (14) Boeing B-52, (15) General Dynamics F-111D.

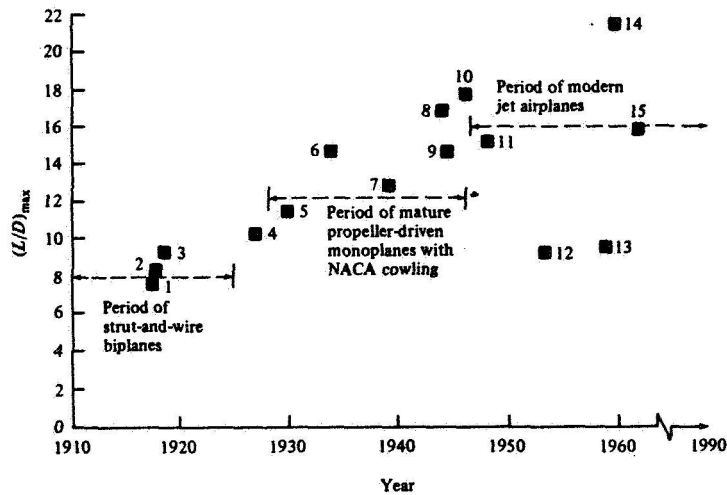
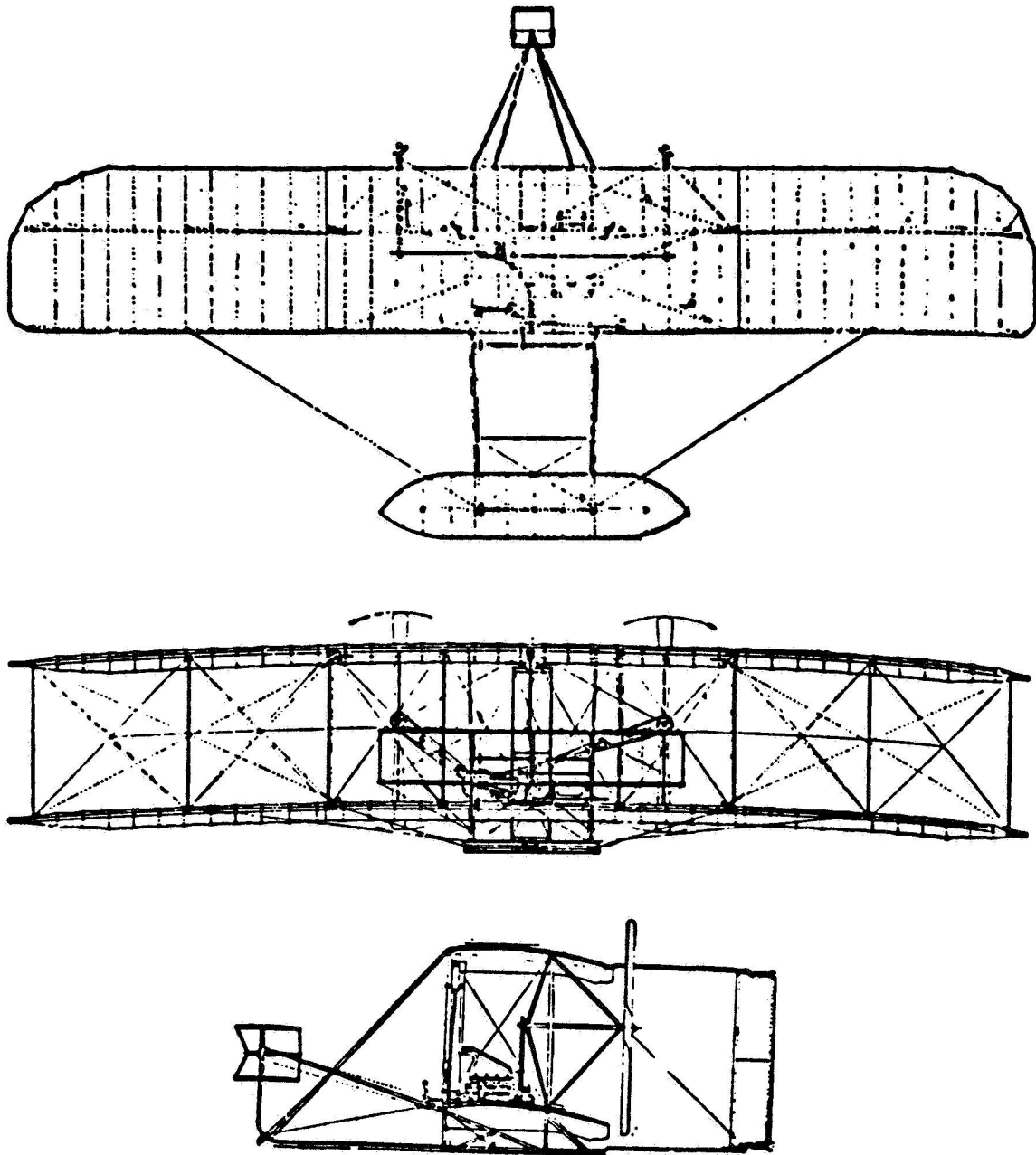
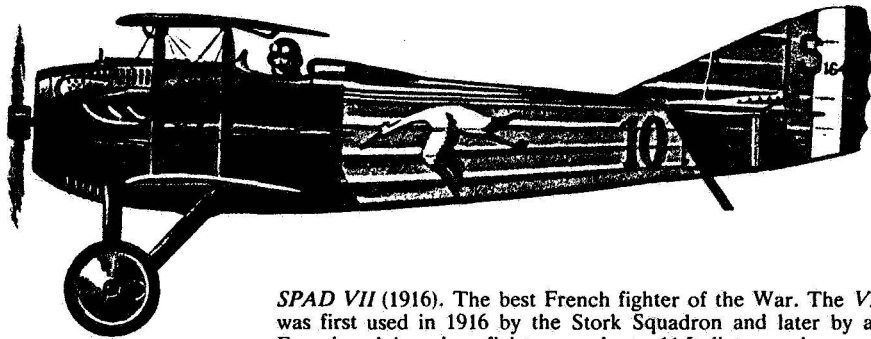


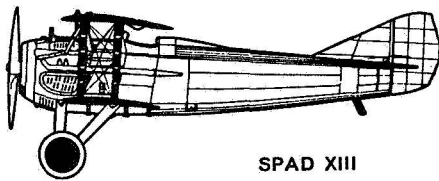
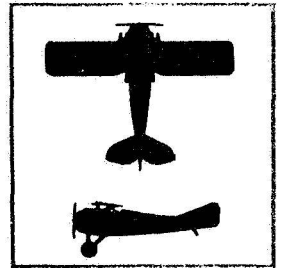
Figure 6.61 Use of lift-to-drag ratio to illustrate three general periods of twentieth-century airplane design.



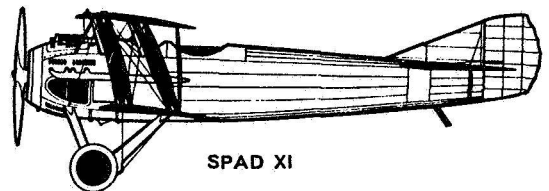
Three views of the Wright Flyer I, 1903.



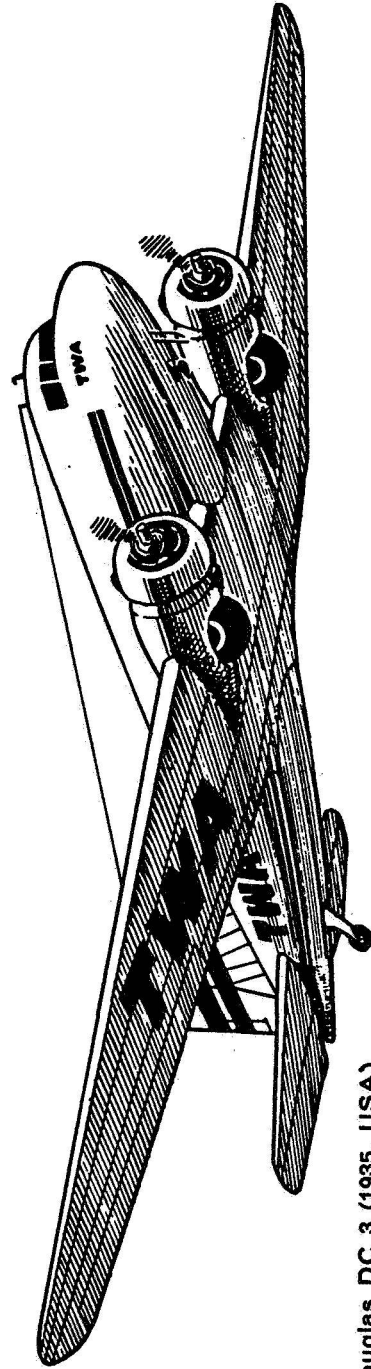
SPAD VII (1916). The best French fighter of the War. The *VII* was first used in 1916 by the Stork Squadron and later by all French and American fighter squadrons, 11 Italian squadrons and one Belgian. In 1917 it was replaced by the faster and better armed *XIII* model. It was the favorite plane of the aces Fonck, Guynemer, Barracca and Rickenbacker. Of the nearly 15,000 *Spads* built, only a few were the *XI* two-seat reconnaissance type.



SPAD XIII

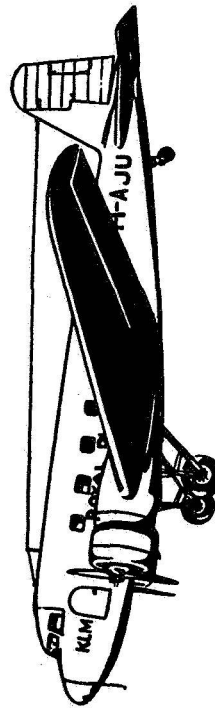


SPAD XI



Douglas DC 3 (1935, USA)

Douglas DC 2 (1934, USA)



The modern and original DC-2 began service in 1934. Two hundred and twenty were built. But its successor, the DC-3, which flew for the first time on December 17, 1935, was to become the most prestigious aircraft in the world. It was used by nearly all civilian airlines and was an essential model for military aviation during the War. About 13,000 were built, of which at least 1000 are still in service today!

Figure 11. Detailed design of the He 178 in 1938.

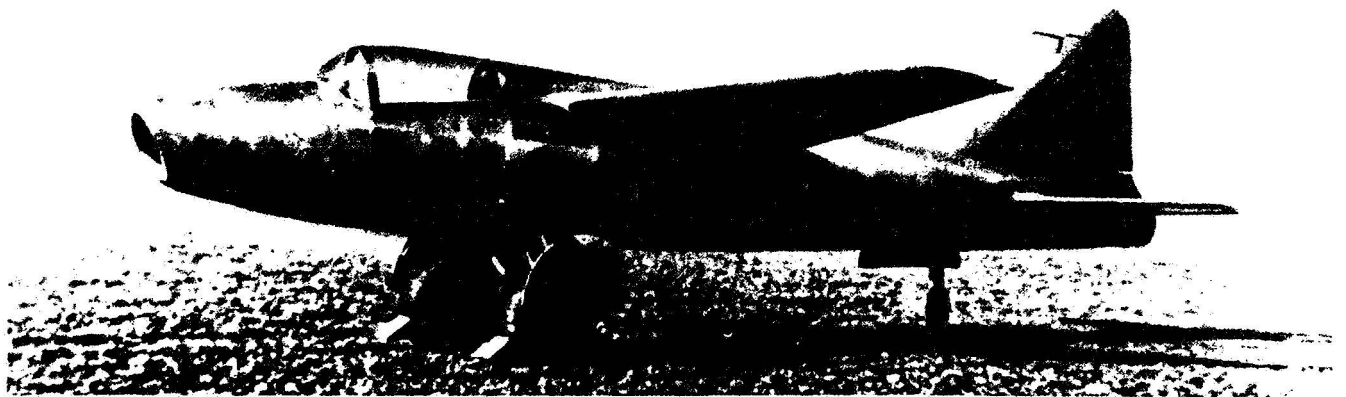
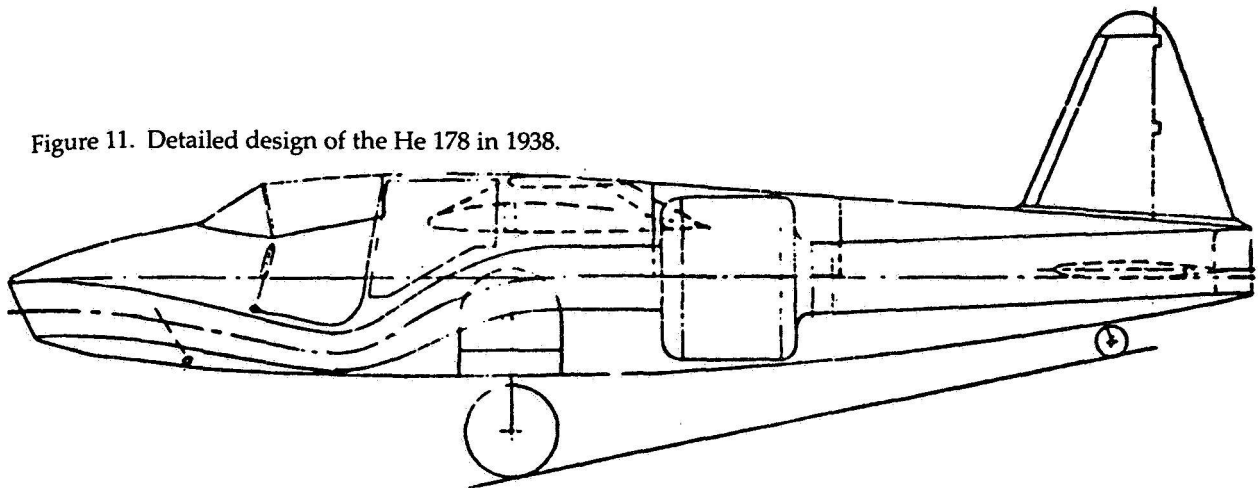
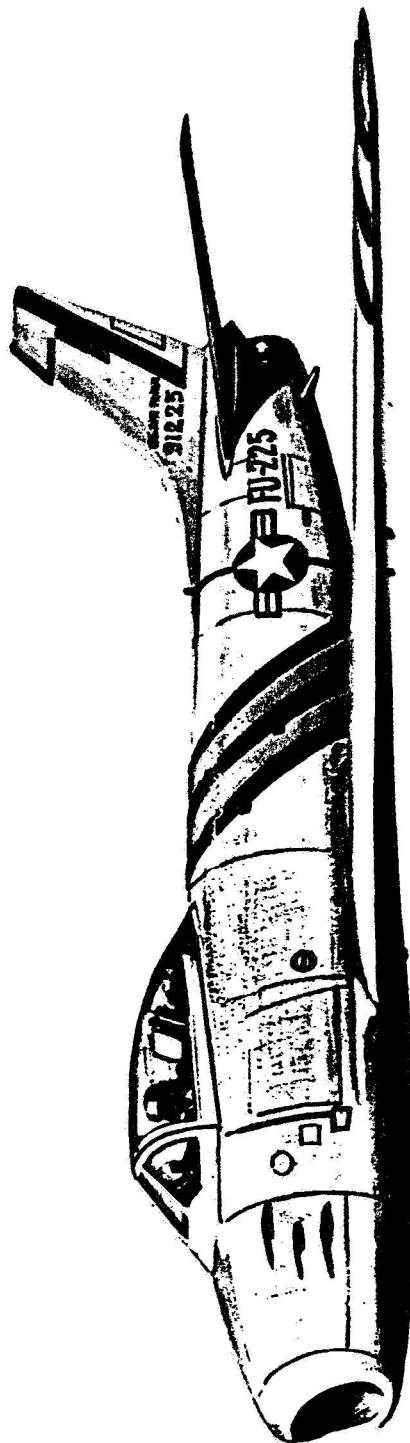
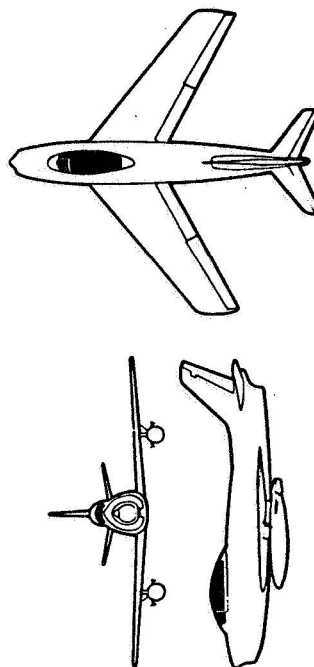
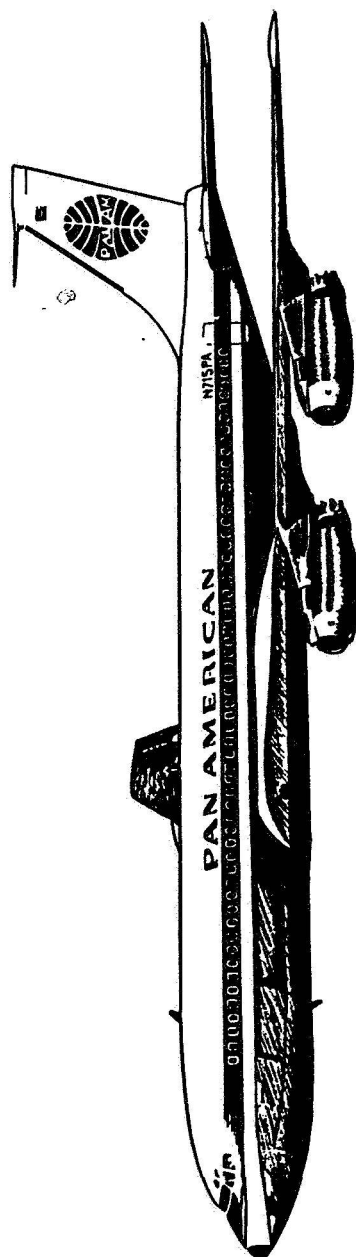


Figure 12. The world's first aircraft to fly purely on turbojet power, the Heinkel He 178. Its first true flight was on August 27, 1939.

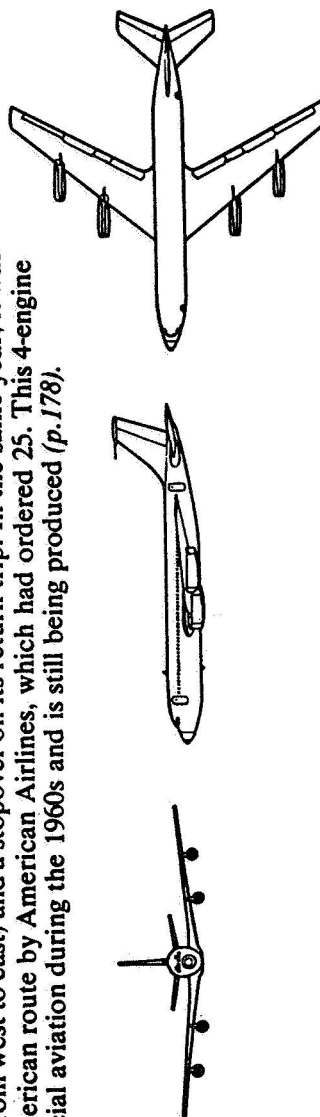


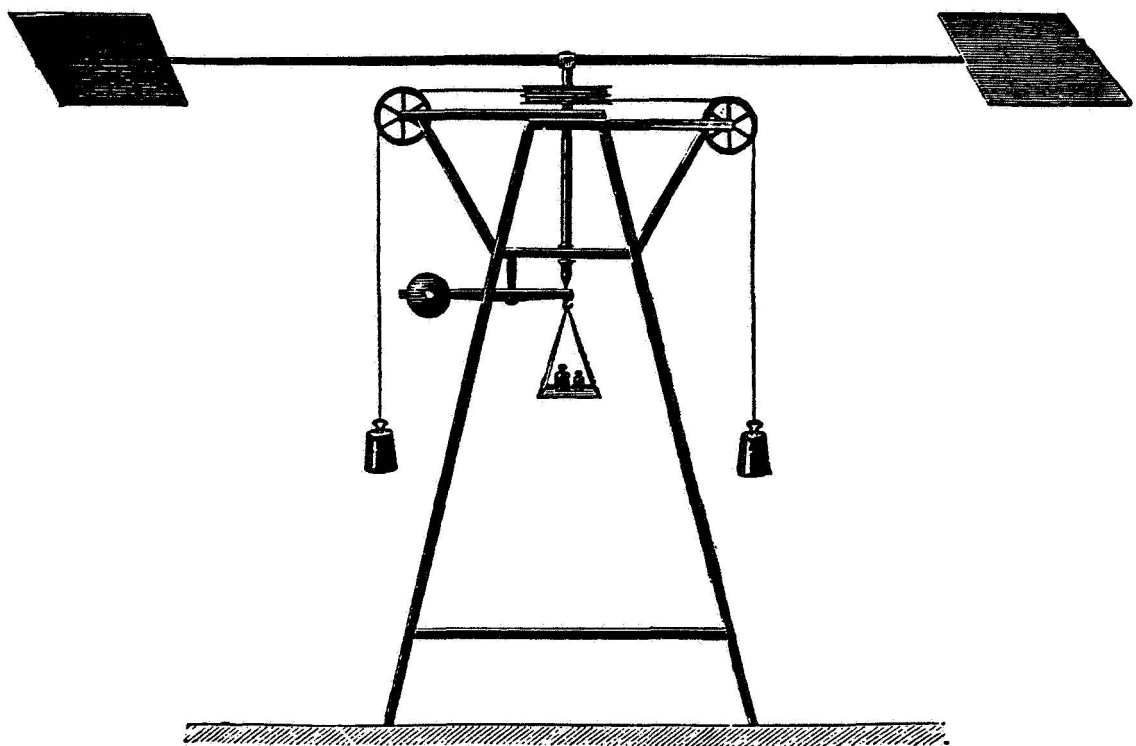
NORTH AMERICAN F-86 SABRE (1949, USA). The first American fighter with swept wings, it flew for the first time on October 1, 1947, and had its baptism by fire in Korea in December 1950, where it fared better than the *P-80* against the Russian *MIG-15*'s. This outstanding aircraft became the standard fighter in the air forces of about 30 countries, European, South American and Asian. It was also built in Canada, Australia, Japan and Italy by Fiat. It was produced in many versions. Production was stopped at the end of the 1950s after about 5800 units had been delivered to Fighter Squadrons of half the world's air forces.



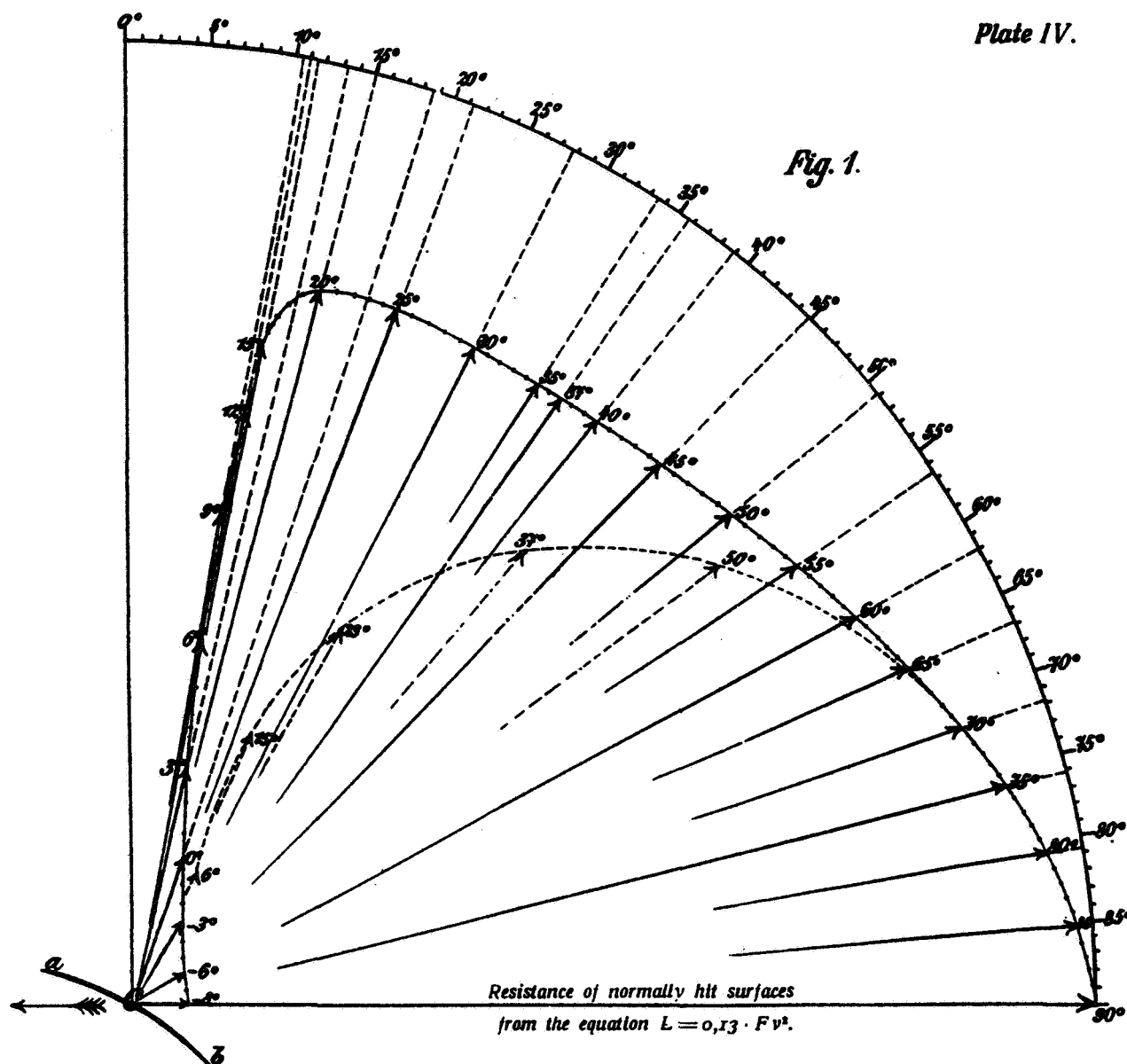


BOEING 707-121 (1958, USA). The prototype of one of the most successful passenger aircraft of all times, the 707 made its first flight on July 15, 1954. On October 26, 1958, Pan American was the first to use it nonstop across the Atlantic to Europe (aided by the favorable winds on flights from west to east) and a stopover on its return trip. In the same year, it was put into service on a transcontinental North American route by American Airlines, which had ordered 25. This 4-engine jet was to become one of the pillars of commercial aviation during the 1960s and is still being produced (*p.178*).





Lilienthal's Whirling Arm



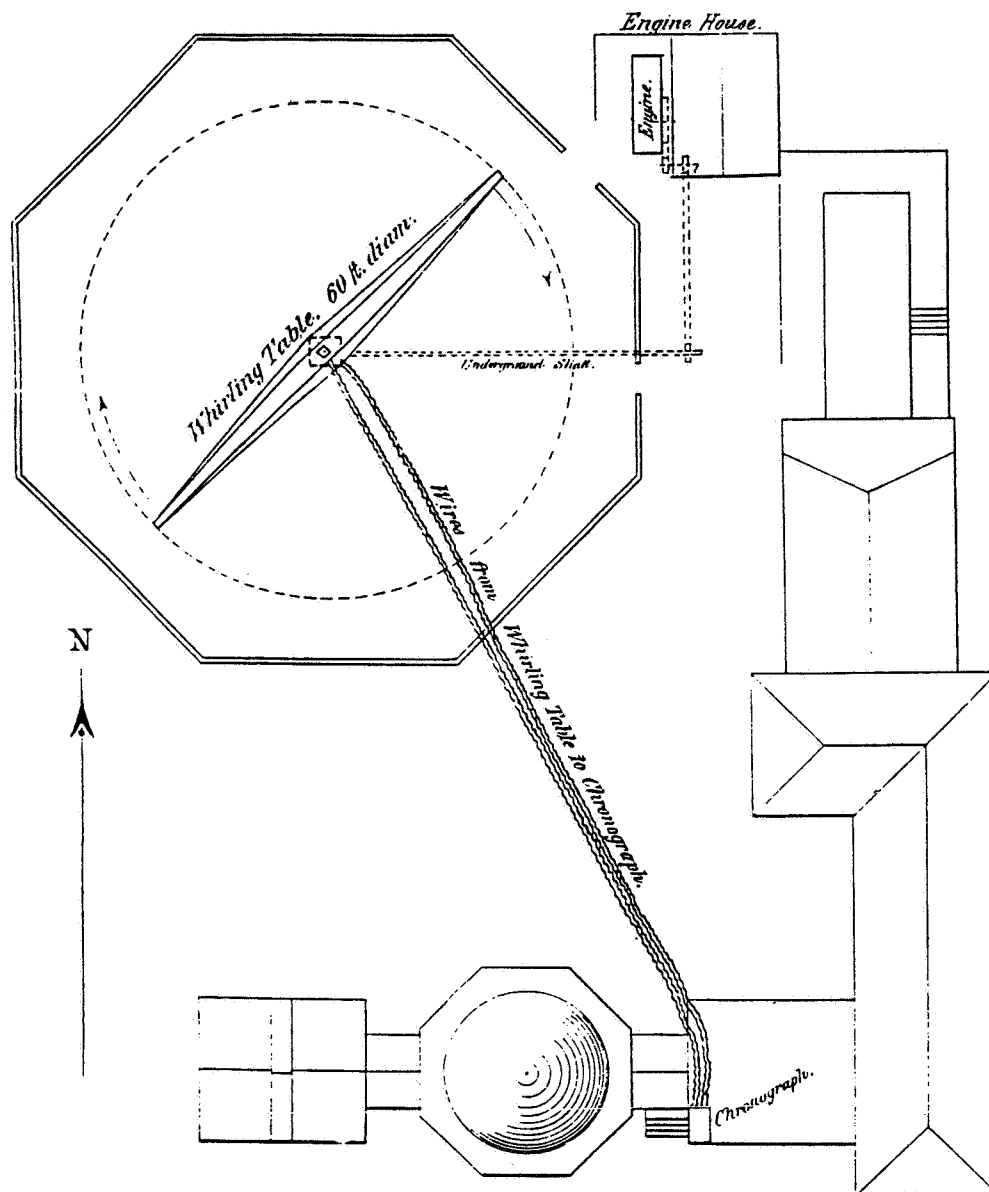
Camber $\frac{1}{12}$ width.

*Air pressure on curved surfaces determined
during rotation in still air.*

The First Drag Polar, Lilienthal--1889

TABLE OF NORMAL AND TANGENTIAL PRESSURES
Deduced by Lilienthal from the diagrams on Plate VI., in his
book "Bird-flight as the Basis of the Flying Art."

α Angle.	η Normal.	ϑ Tangential.	α Angle.	η Normal.	ϑ Tangential.
- 9°	0.000	+ 0.070	16°	0.909	- 0.075
- 8°	0.040	+ 0.067	17°	0.915	- 0.073
- 7°	0.080	+ 0.064	18°	0.919	- 0.070
- 6°	0.120	+ 0.060	19°	0.921	- 0.065
- 5°	0.160	+ 0.055	20°	0.922	- 0.059
- 4°	0.200	+ 0.049	21°	0.923	- 0.053
- 3°	0.242	+ 0.043	22°	0.924	- 0.047
- 2°	0.286	+ 0.037	23°	0.924	- 0.041
- 1°	0.332	+ 0.031	24°	0.923	- 0.036
0°	0.381	+ 0.024	25°	0.922	- 0.031
+ 1°	0.434	+ 0.016	26°	0.920	- 0.026
+ 2°	0.489	+ 0.008	27°	0.918	- 0.021
+ 3°	0.546	0.000	28°	0.915	- 0.016
+ 4°	0.600	- 0.007	29°	0.912	- 0.012
+ 5°	0.650	- 0.014	30°	0.910	- 0.008
+ 6°	0.696	- 0.021	32°	0.906	0.000
+ 7°	0.737	- 0.028	35°	0.896	+ 0.010
+ 8°	0.771	- 0.035	40°	0.890	+ 0.016
+ 9°	0.800	- 0.042	45°	0.888	+ 0.020
10°	0.825	- 0.050	50°	0.888	+ 0.023
11°	0.846	- 0.058	55°	0.890	+ 0.026
12°	0.864	- 0.064	60°	0.900	+ 0.028
13°	0.879	- 0.070	70°	0.930	+ 0.030
14°	0.891	- 0.074	80°	0.960	+ 0.015
15°	0.901	- 0.076	90°	1.000	0.000



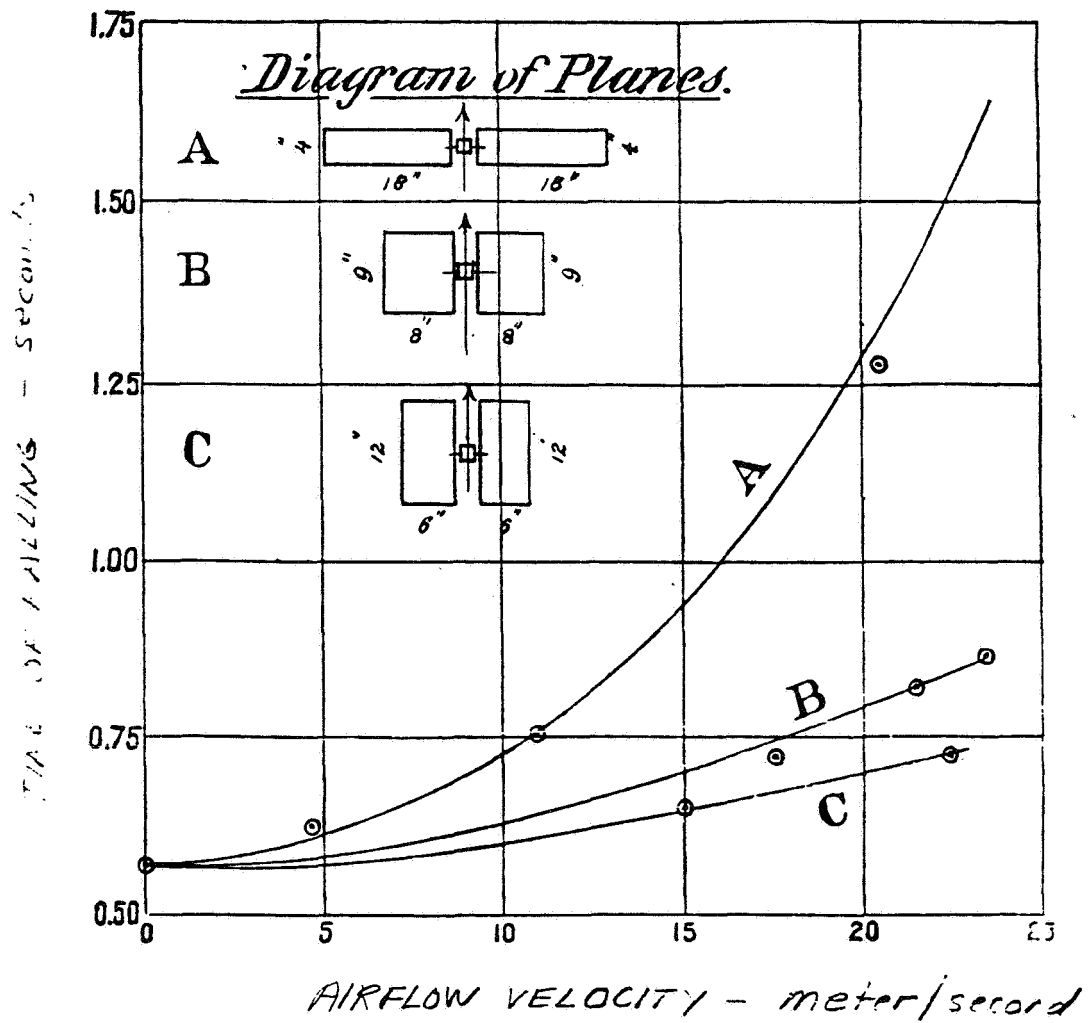
ALLEGHENY OBSERVATORY.

Plan of Grounds.

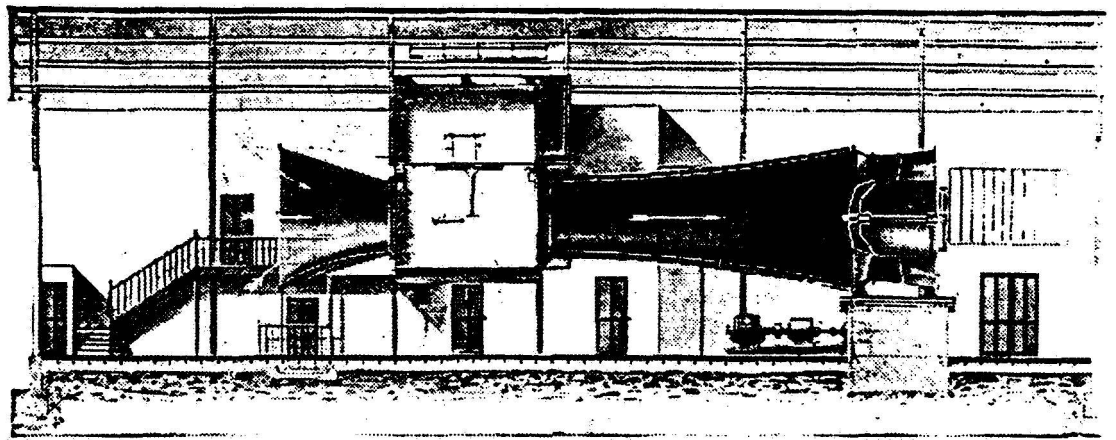
SCALE: 1 INCH = 20 FEET

Langley's Whirling Arm--1887

WEIGHT OF MODELS : 0.465 kilogram

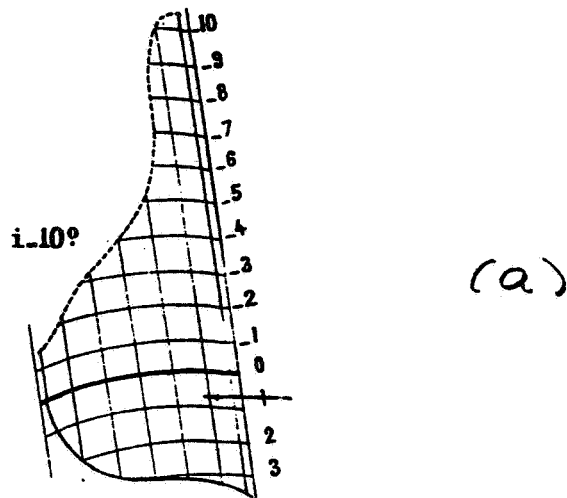


From Langley, Experiments in Aerodynamics, 1891

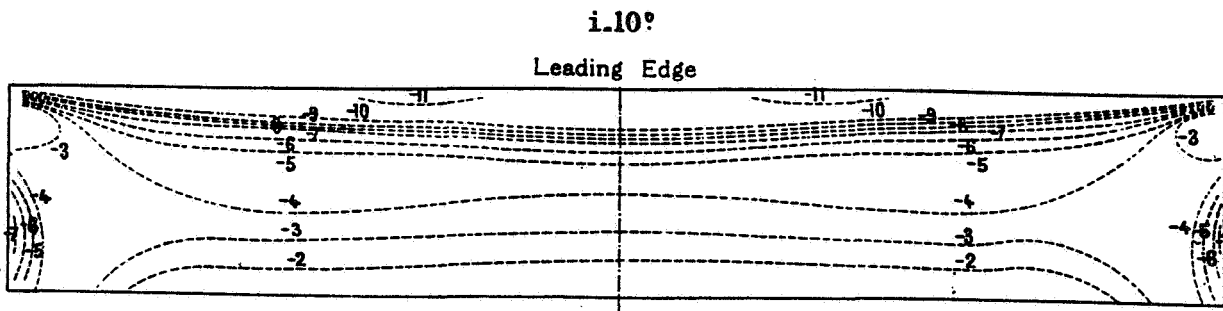


Eiffel's Wind Tunnel (His Second Tunnel)--1912

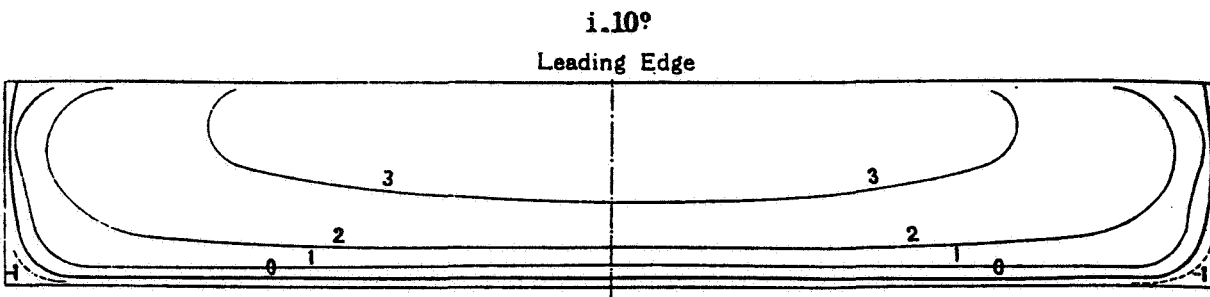
Pressure along centre line



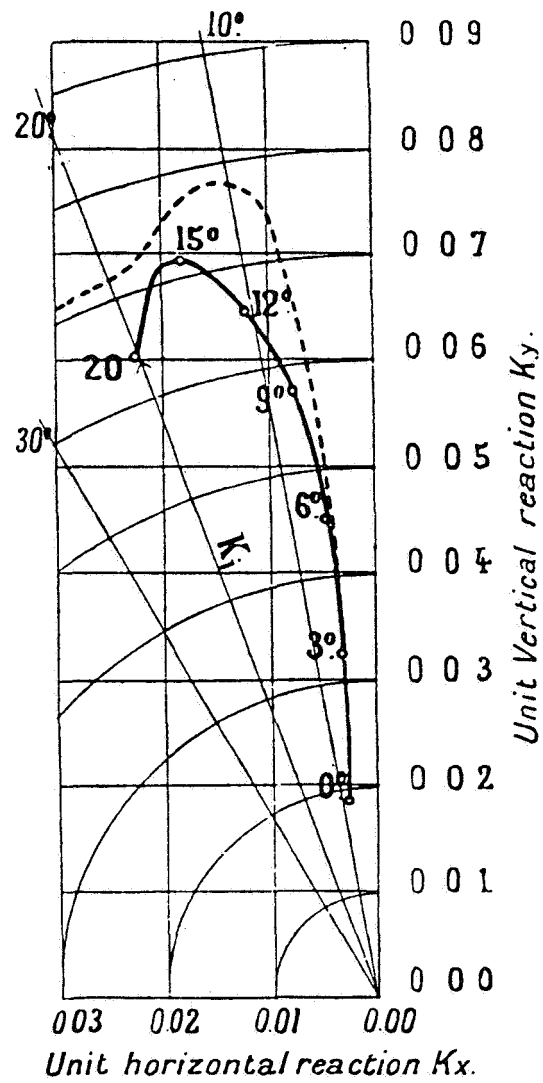
Curves of equal pressure on back



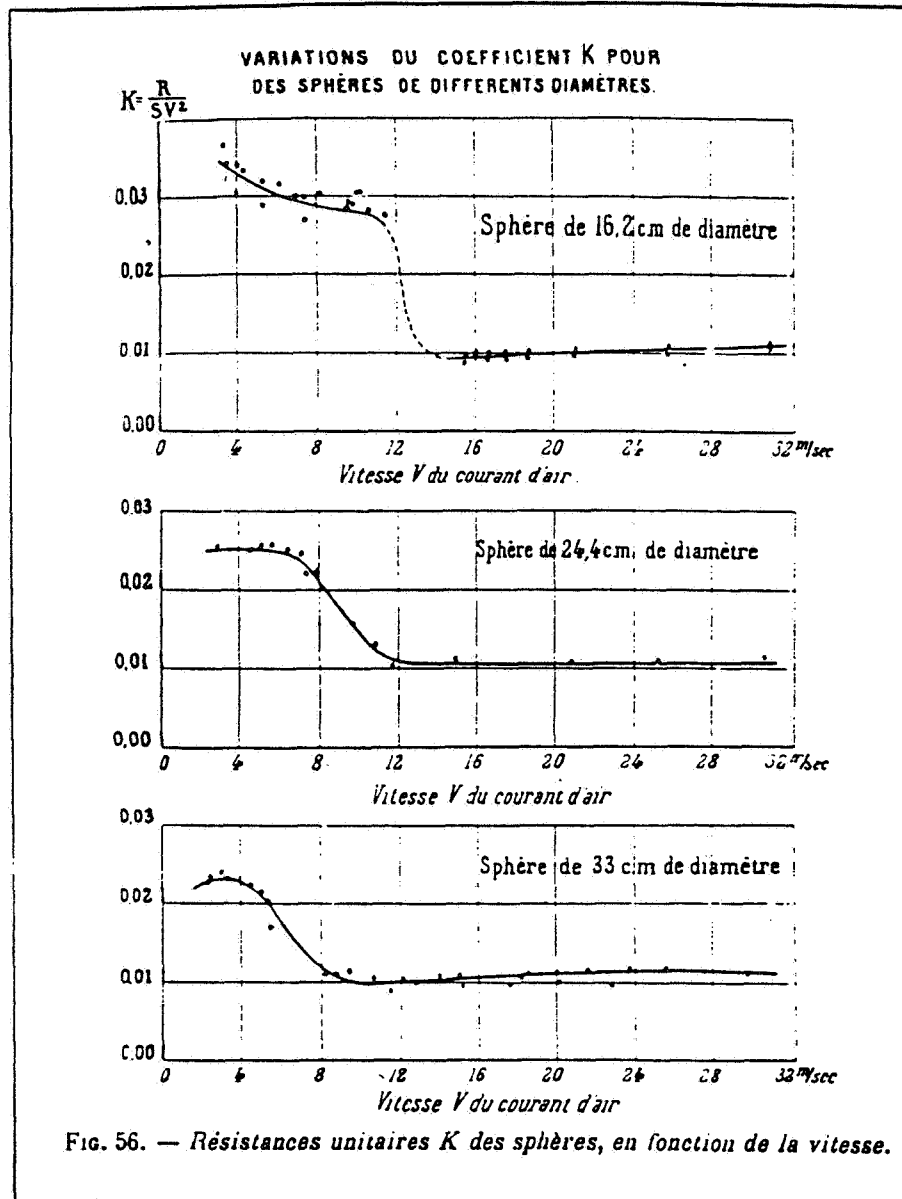
Curves of equal pressure on face



Pressure Contours, Eiffel--1910

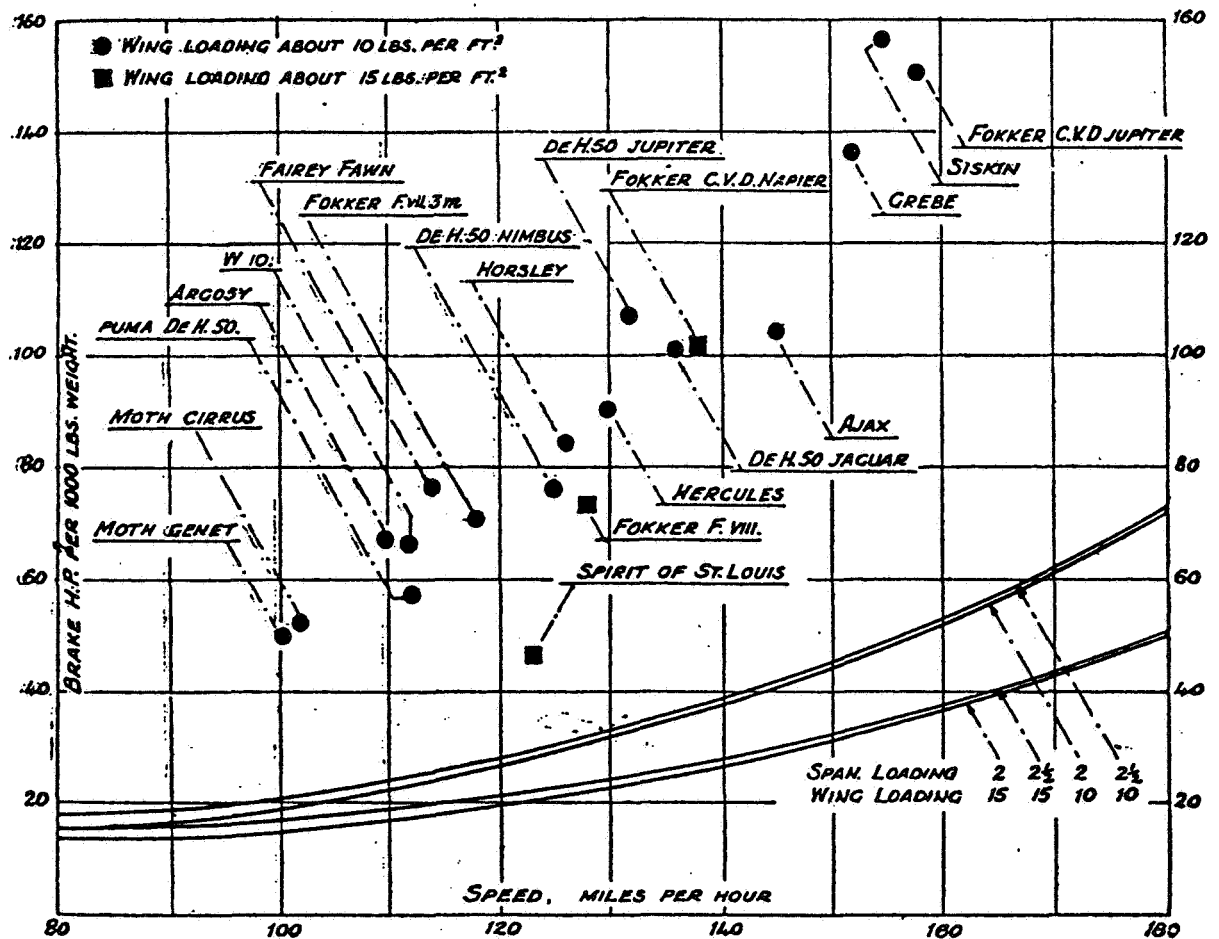


Drag Polar for the Wright Type A Wind, Data from Eiffel--1910



Sphere Drag Coefficient, Measurements from Eiffel--c. 1915

COMPARISON BETWEEN REAL AND STREAMLINE AEROPLANE.
FIGURES FROM 1927 JANE. TOP SPEED:



Melvill Jones's Ideal Airplane--1929

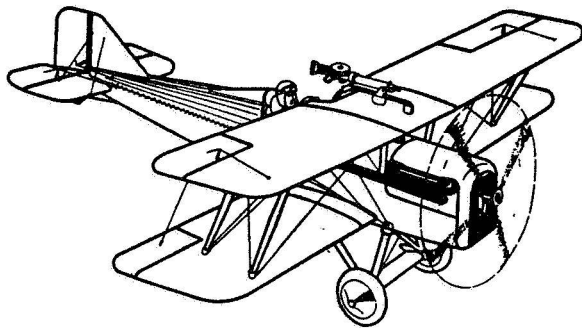


FIG. 1.

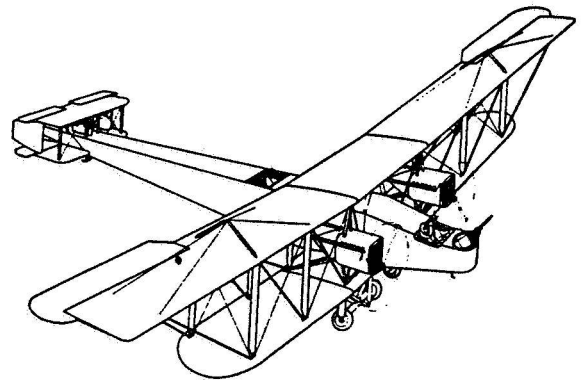


FIG. 4.

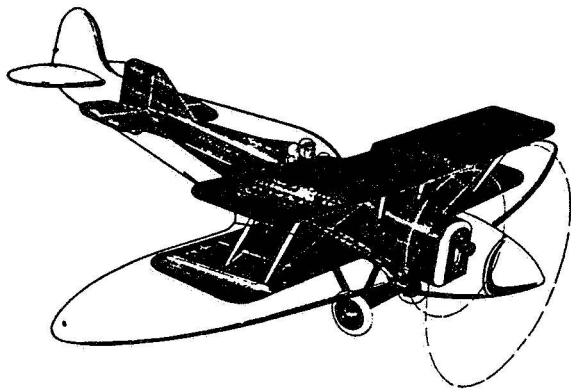


FIG. 2.

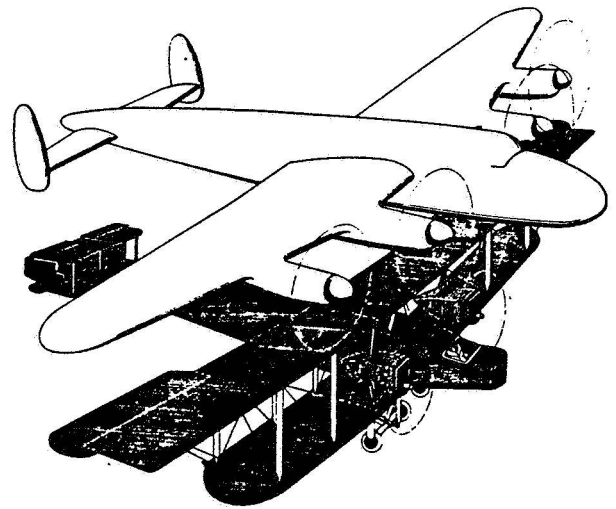


FIG. 5.

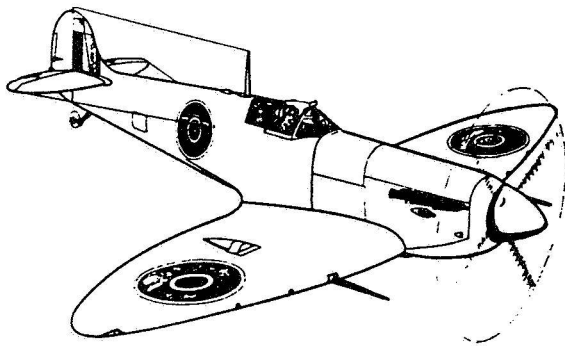


FIG. 3.

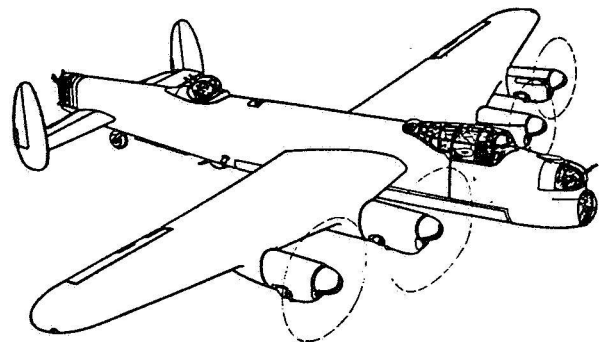
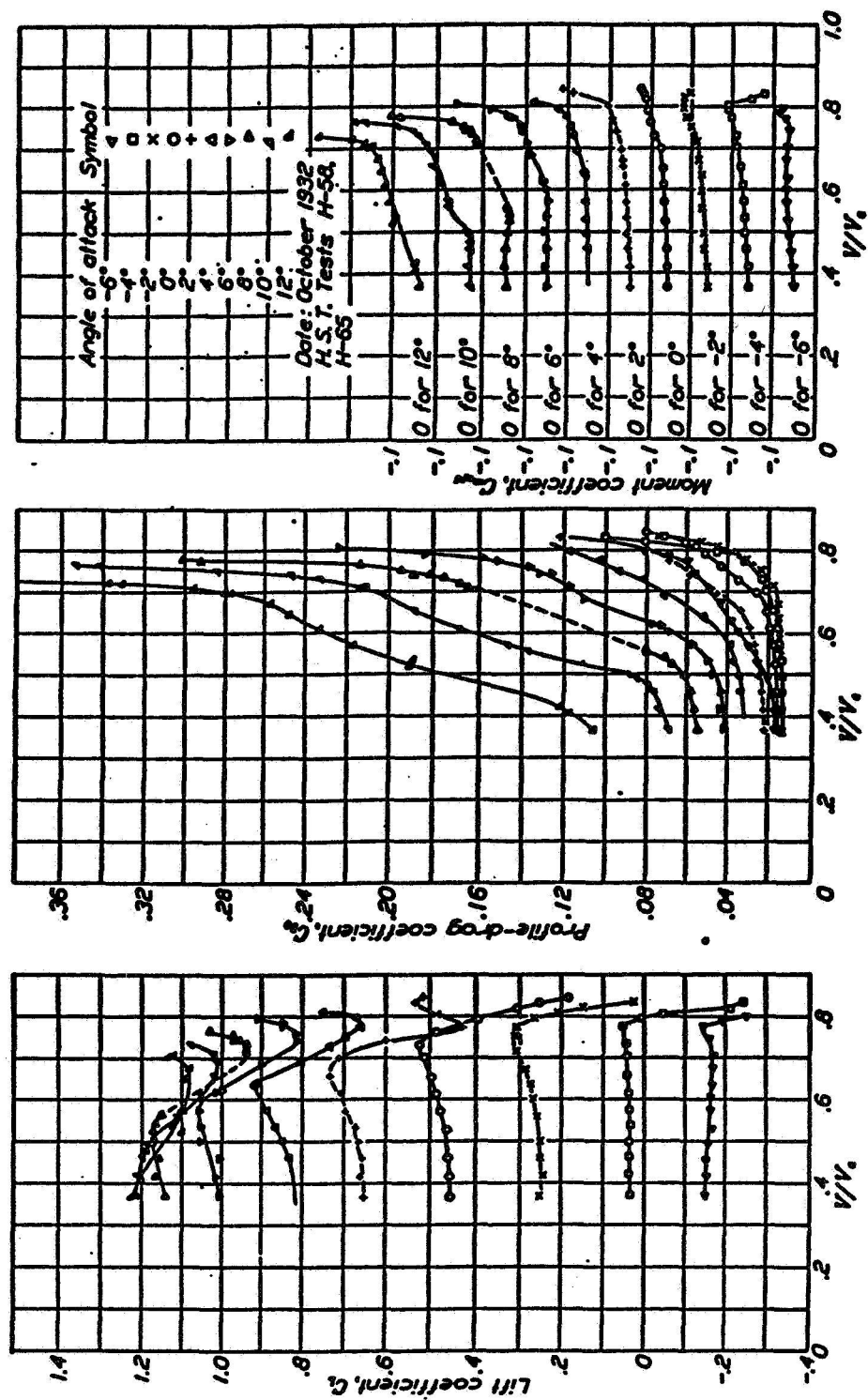
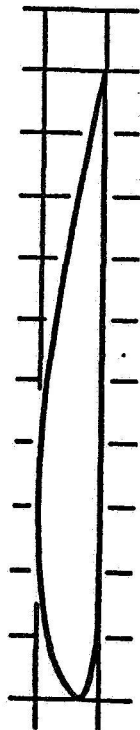


FIG. 6.

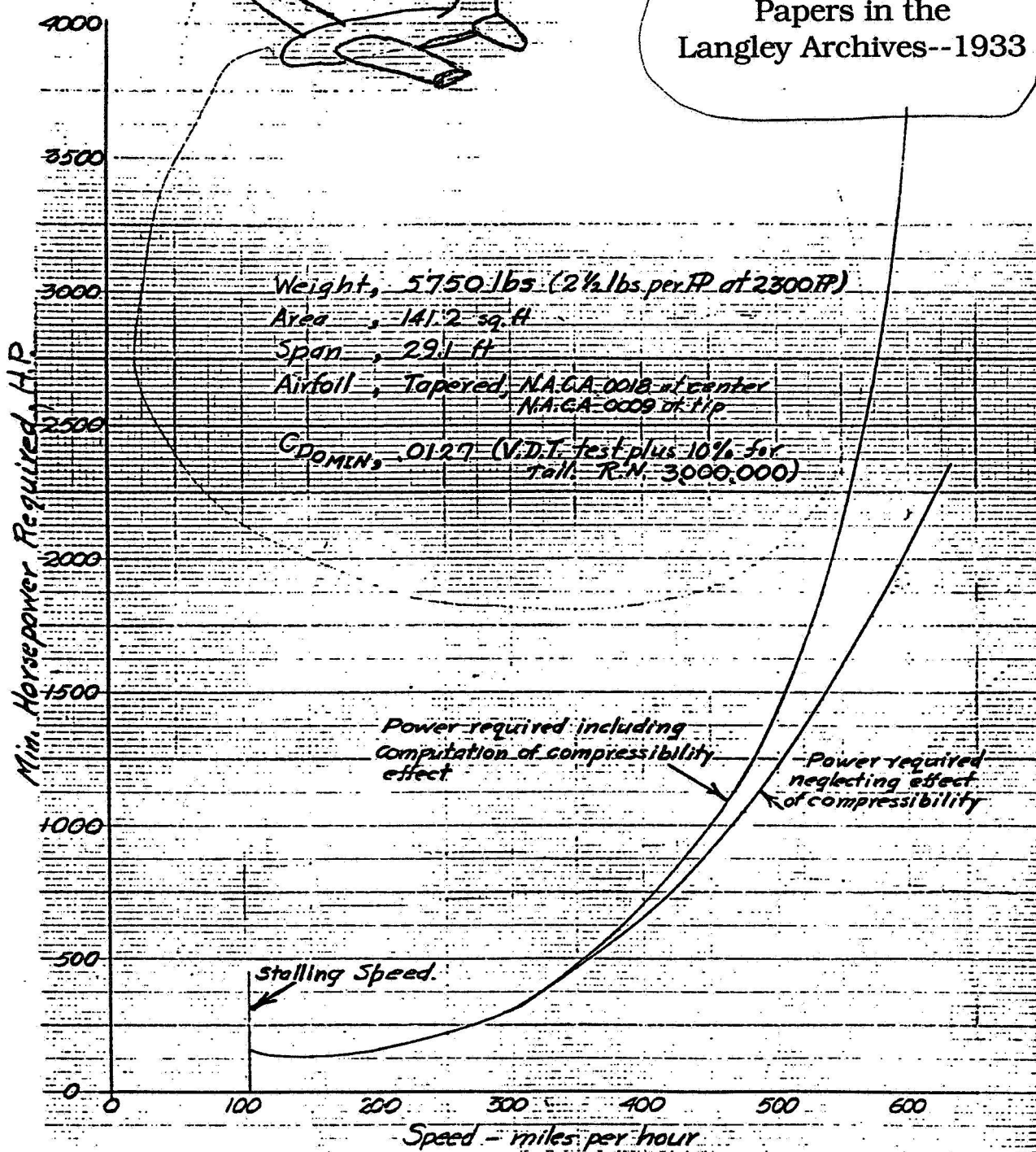
From Farren, Evolution of Streamlining, 7th Wright Brothers' Lecture, 1943, (IAS) Journal of the Aeronautical Sciences, April 1994



Wind Tunnel Data--John Stack, NACA, 1932

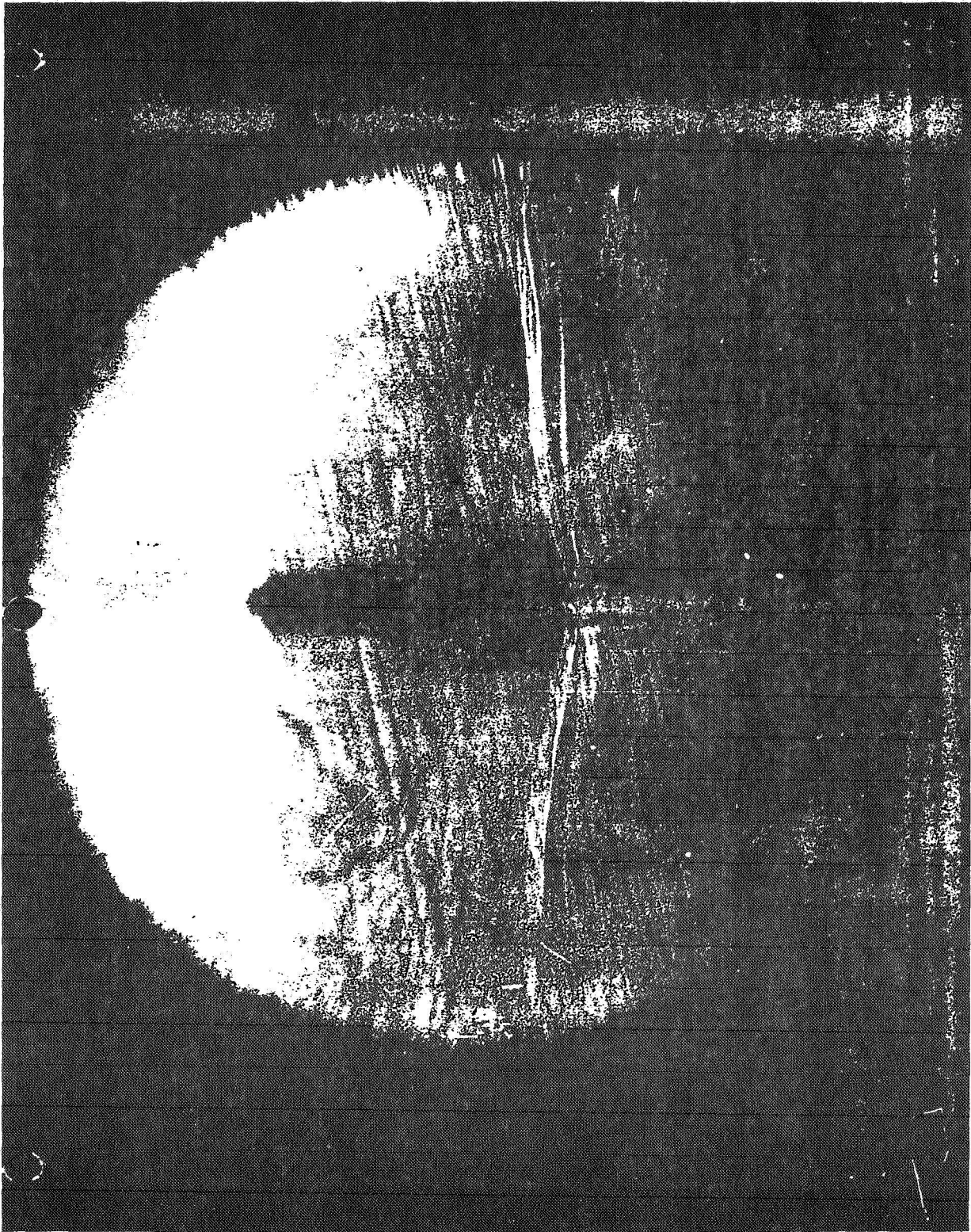
EFFECT OF COMPRESSIBILITY IN HIGH SPEED FLIGHT.

From John Stack
Papers in the
Langley Archives--1933

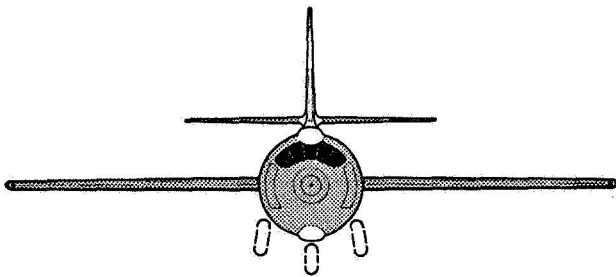


NATIONAL ADVISORY

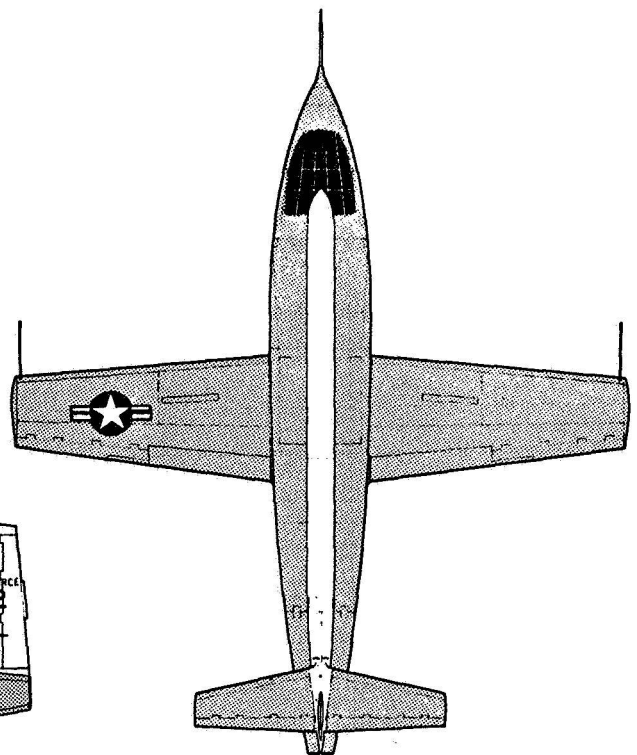
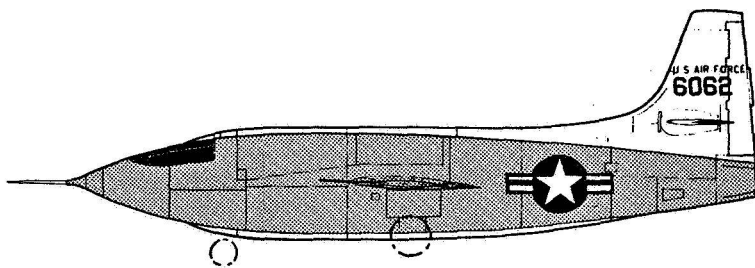
Schlieren Photo, Shock Waves on an NACA 0012 Airfoil--1934



Bell X-1 (First Generation)



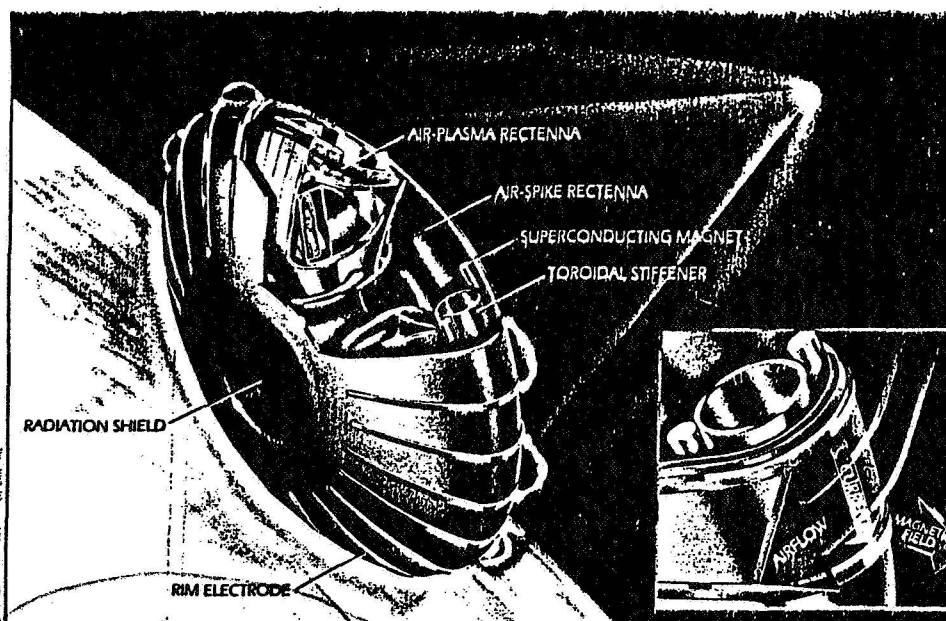
Colors:
F.S. 12243 gloss orange over-all w/F.S. 17925
gloss white trim



SCIENCE

Fly By Microwaves

BY GREGORY T. POPE, Science/Technology Editor



● Engineers come in two varieties. Some push the envelope from within, squeezing every last advantage out of existing technology. Their insights can turn a desktop computer into a notebook, or a Ford Fairlane into a Taurus. Without them, for sure, we'd be leading poorer lives.

But then there are engineers who perch outside the envelope and stir up trouble. Impatient with the pace of progress, they stretch for undeveloped technologies, mix and match nascent concepts and challenge the world to prove them wrong. They endure condescension while they're working out their ideas. But if their ideas do work out, they're lauded as visionaries.

Put Leik Myrabo into this second category. An associate professor of mechanical engineering at Rensselaer Polytechnic Institute, in Troy, New York, Myrabo is rewriting the laws of flight. But he's not tinkering with jet or rocket engines. Nor is he reformulating fuels or propellants. Instead, he's blueprinting a vehicle that does nothing less than streak into the sky on a beam of microwaves.

For more than a decade, Myrabo has pursued a vision he calls "Highways of Light." The concept began as a means of boosting a spacecraft without burdening it with fuel (see Tech Update, page 21, April '90). Shining up from the ground, a heavy-duty

laser would illuminate the spacecraft's lower surface. The barrage of energy would break air molecules into plasma—a blazing vapor of ions, or charged particles. The explosive expansion that accompanied this ionization would shove the vehicle skyward.

In experiments with scale models, the technique proved capable of imparting thrust. But the Strategic Defense Initiative Organization, which helped bankroll Myrabo's research, soon pulled the plug on 100-megawatt-laser development.

Unfazed, Myrabo joined forces with Yuri Raizer of the Russian Academy of Sciences. The Space Studies Institute, in Princeton, New Jersey, picked up the funding. Myrabo recalls the Institute's reasoning: "They said, 'We love your lasercraft, but we're still waiting for the high-powered lasers. High-powered microwave sources are here now—is it possible to design something around them?'"

The switch from laser to less energetic microwave power sent Myrabo and Raizer scurrying for ideas. As is often the case, the wealth of unexploited aerospace theory from the 1950s and 1960s proved a fertile hunting ground. Within weeks, the engineers concocted a fresh design, a disc-shaped vehicle called a microwave lightcraft. Myrabo has since refined the design into one that brims with

exciting, albeit untried, technologies.

Take the propulsion system, for example. Instead of simply riding a wave of expanding plasma, the lightcraft would wield electromagnetic forces to whisk the plasma past itself.

The driving force begins as a shaft of pulsed microwave energy. This beam showers the lightcraft from an overhead satellite that converts sunlight into microwaves. The energy hits two rectifying antennas, or rectennas, that lie beneath the vehicle's

microwave-transparent surface. These antennas, in turn, convert much of the microwave energy into electrical power. At the same time, they work like lenses to focus the rest to points outside the spacecraft.

Shaped like a shallow, curved lampshade, one of the rectennas rings the craft. This air-plasma rectenna drives the craft at subsonic speeds. It focuses the incoming microwaves into an ignition circle around the vehicle's periphery. There, the microwaves blast air into plasma.

As the plasma expands, it gets caught up in electromagnetic fields from two superconducting magnets that encircle the craft. Their relative strengths being adjustable, these fields can form a magnetic nozzle that propels the plasma downward, imparting lift to the spacecraft.

Futuristic enough? Yet at supersonic speeds, an even more radical propulsion method takes over. In this mode, the other rectenna—located on the lightcraft's upper face—joins in. It focuses part of the microwave beam back ahead of the vehicle, forming a conical reflection known as an air spike. Like the pointed nose of a fighter jet, this cone reduces aerodynamic drag, keeping a shock wave from hammering the vehicle's flat upper surface. Instead, the shock wave arches around the air spike. In

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“The power of knowledge, put it to the task,
No barrier will be able to hold you back,
It will support you even in flight!
It cannot be your Creator’s desire
To chain his finest in the muck and mire,
To eternally deny you flight!”

Poem by Otto Lilienthal, in his book
Birdflight as the Basis of Aviation. 1889

These lines are engraved into a
commemorative stone which marks the
site of Lilienthal’s crash at Gollenberg,
Germany

In Search of Cybernautics

Steven Crow
Aerospace and Mechanical Engineering Department
The University of Arizona

Presented at the NASA Langley Research Center
Transportation Beyond 2000 Workshop
26 September 1995

52-01
39467

Progress in Information Technology

Microprocessor performance has increased by factor of 25,000 since 1971 (Intel 4004 to Pentium 120).

Rate of increase has been 52% per year.

Rate has accelerated to 58% over past 5 years.

Performance multiplies by 10 every 5 years.

The Two Cultures

We Know All about These

$$\mathbf{f} = m\mathbf{a}$$

$$L = \rho U \Gamma$$

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho \mathbf{u} \cdot \nabla \mathbf{u} + \nabla p = \mu \nabla^2 \mathbf{u}$$

But What about This One?

$$C = B \log_2 \left[1 + \frac{S}{N} \right]$$

Data Rates

(bps = bits per second)

Device	Bandwidth	Bits	Data Rate
Modem			28.8 Kbps
CD-ROM			5.6 Mbps
Ethernet			10.0 Mbps
Cable TV	4.2 MHz	8	33.6 Mbps
Hard Disc			133.6 Mbps
Video Card	140 MHz	8	1.12 Gbps
P120 CPU	120 MHz	32	3.84 Gbps

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Video Card	140 MHz	8	1.12 Gbps
P120 CPU	120 MHz	32	3.84 Gbps
Human Eyes	400 MHz	10	4.00 Gbps

Aviation Now

Air

Expert pilots
Manual controls
Multiple nav aids
Waypoint navigation
See and avoid under VFR
Voice communication with ATC
No communication with other aircraft

Ground

Expert controllers
Radar and Mode S sensors
Voice communication with aircraft

GPS Navigation and Control Tests

University of Arizona

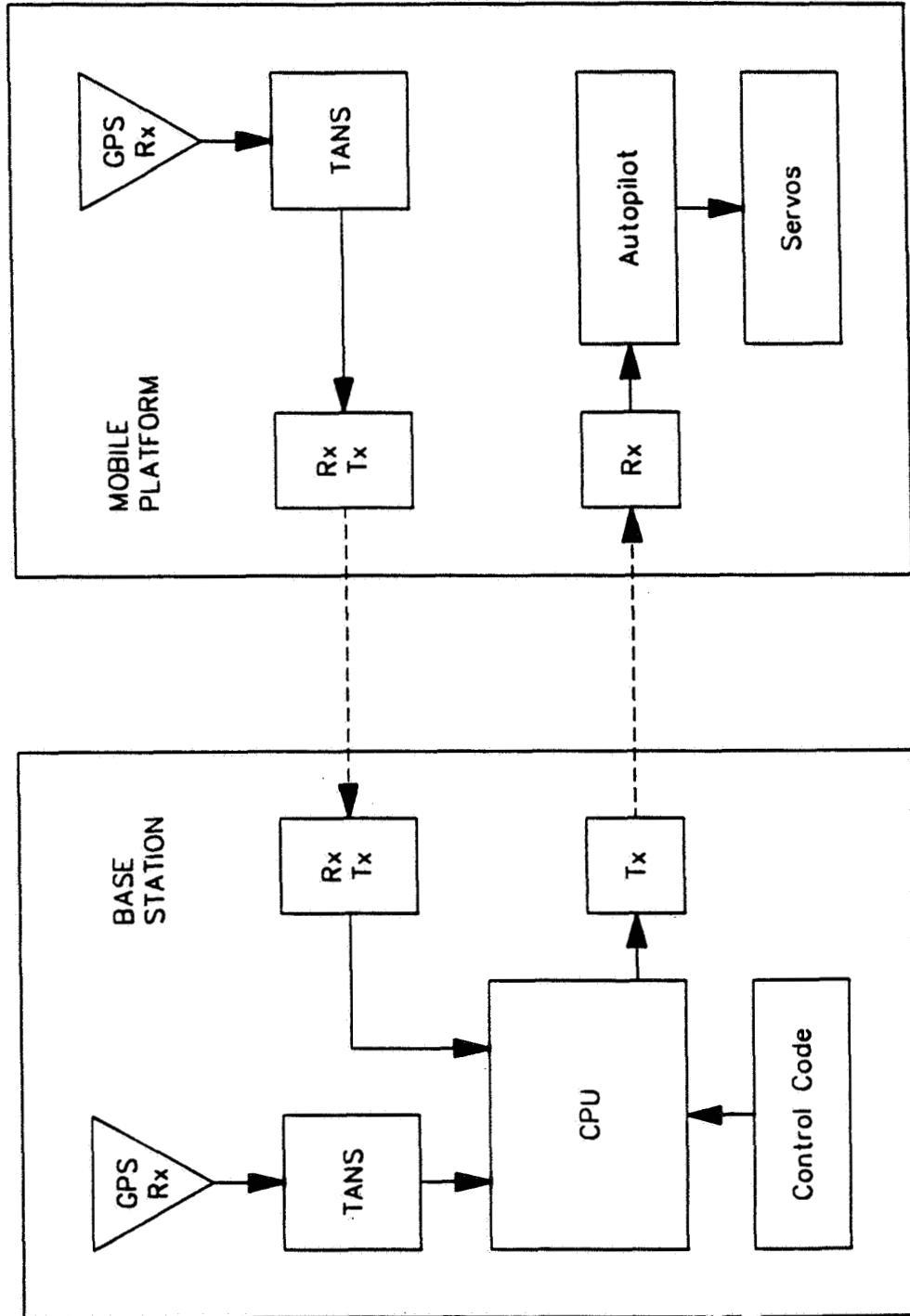
El Cuervo 2

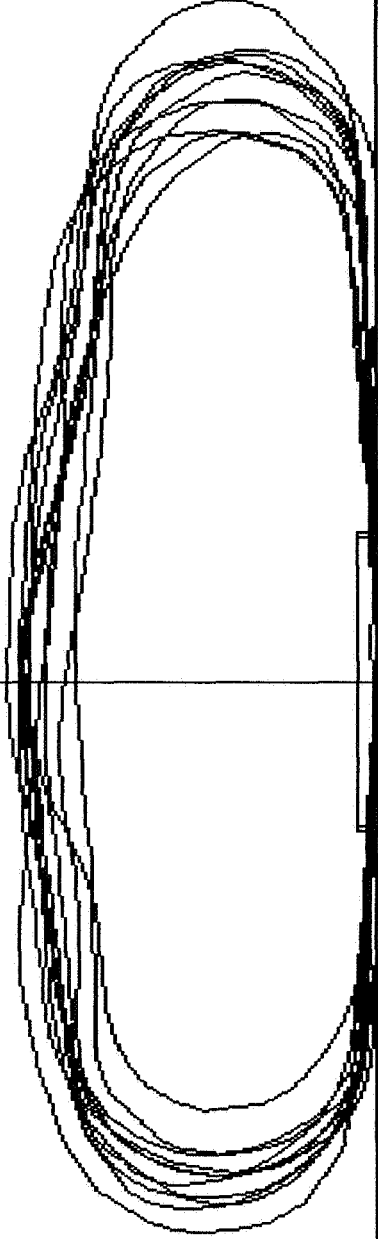
Stanford University

Paul Montgomery's Model Aircraft
Piper Dakota and Wide Area Augmentation System
Piper Dakota and Kinematic GNSS Landing System

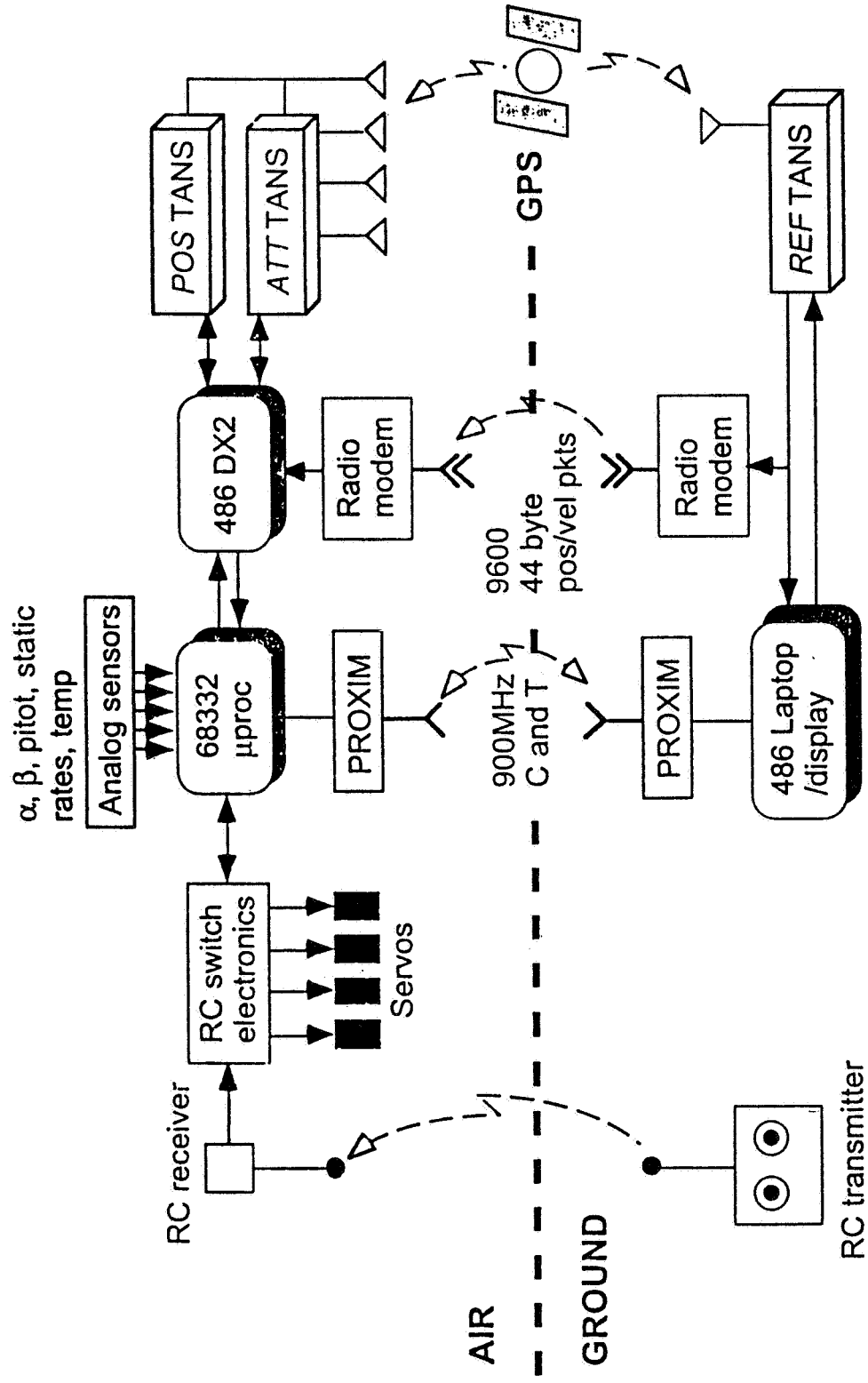
NASA Ames Research Center

King Air Precision Landings with DGPS/INS

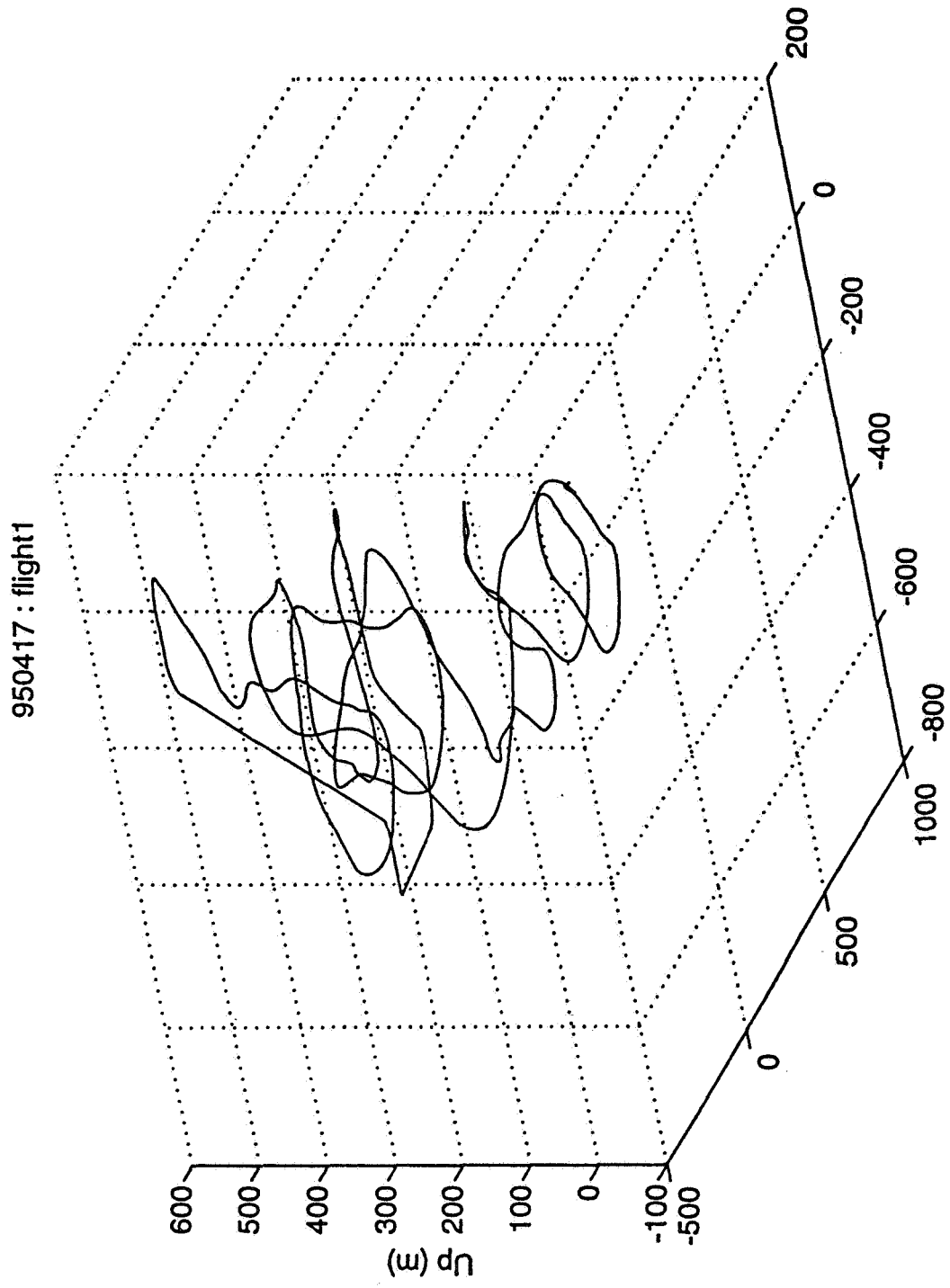


El Cuervo Test Flight, Run # 8 Plan View  The plan view shows a series of overlapping, elongated oval tracks. A small rectangular box is positioned at the center of the tracks, representing the vehicle's location during the test flight.	8:25:22 08-05-95
Delx = 2800 ft Dely = 1400 ft Delz = 631 ft	Veh Sats 2 5 7 12 Base Sats 2 5 7 12
Side View  The side view shows a series of overlapping, elongated oval tracks, similar to the plan view, but from a different perspective, highlighting the vertical profile of the flight path.	

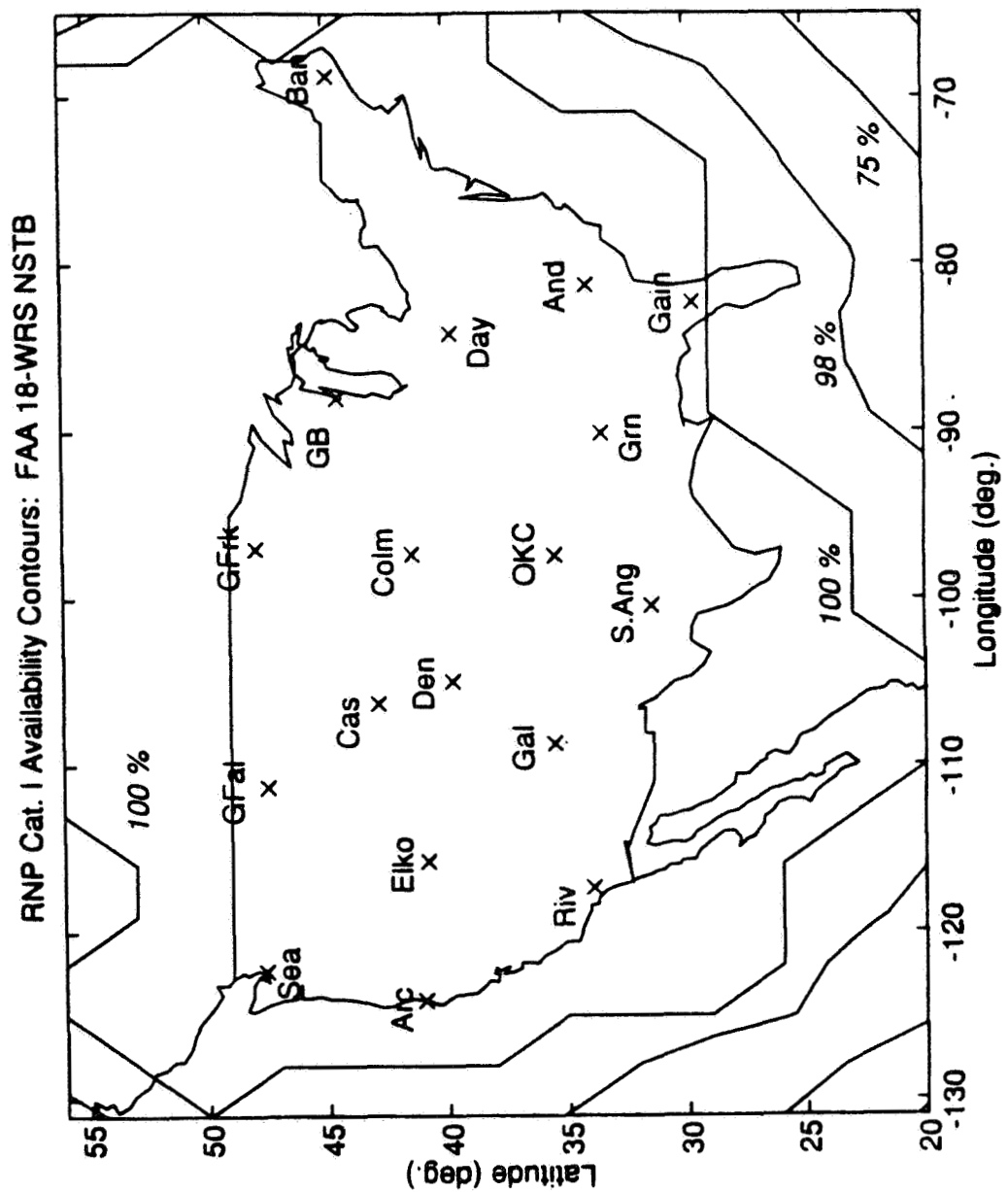
Stanford Model Aircraft Navigation and Control System



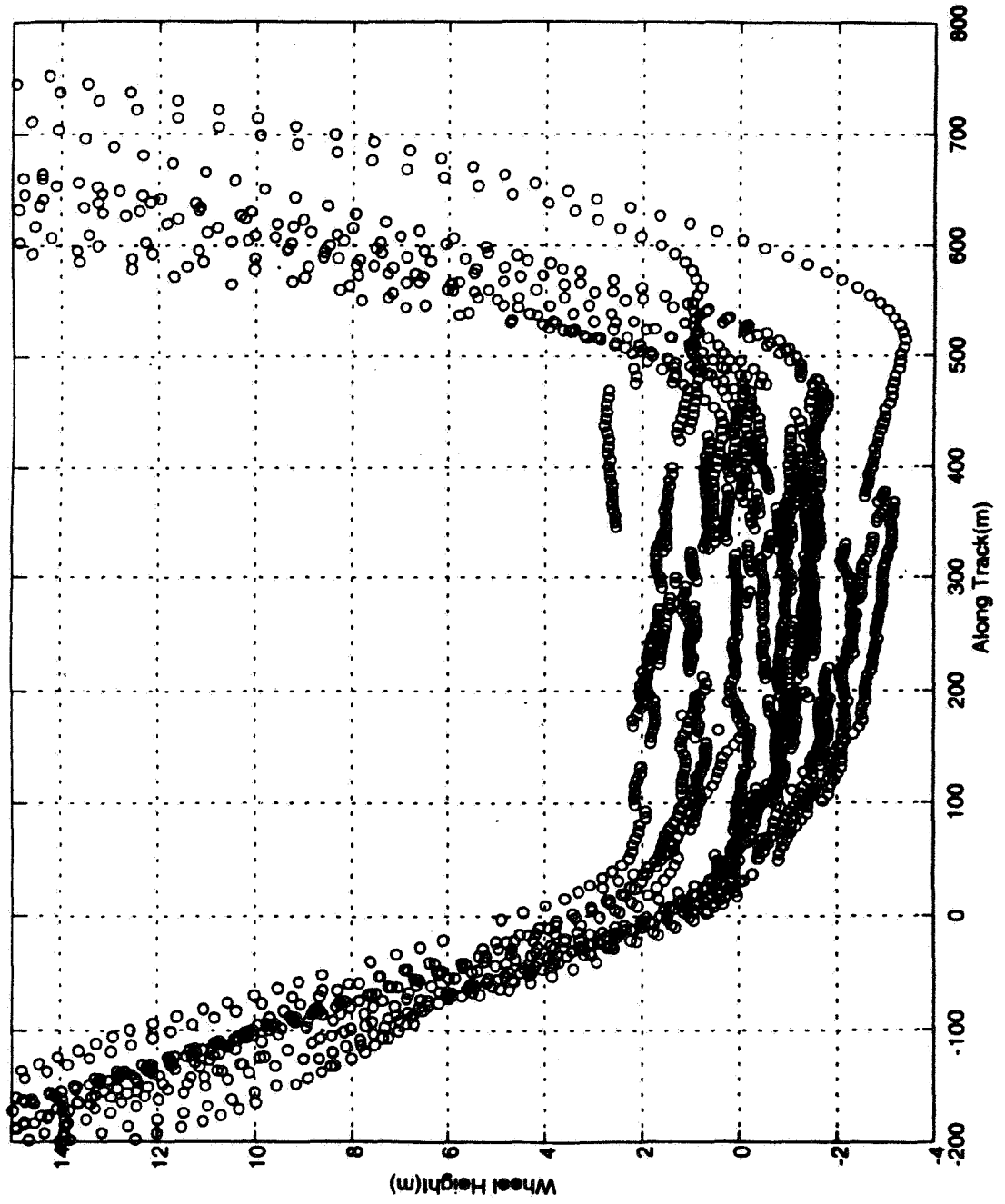
Model Aircraft Flight Path



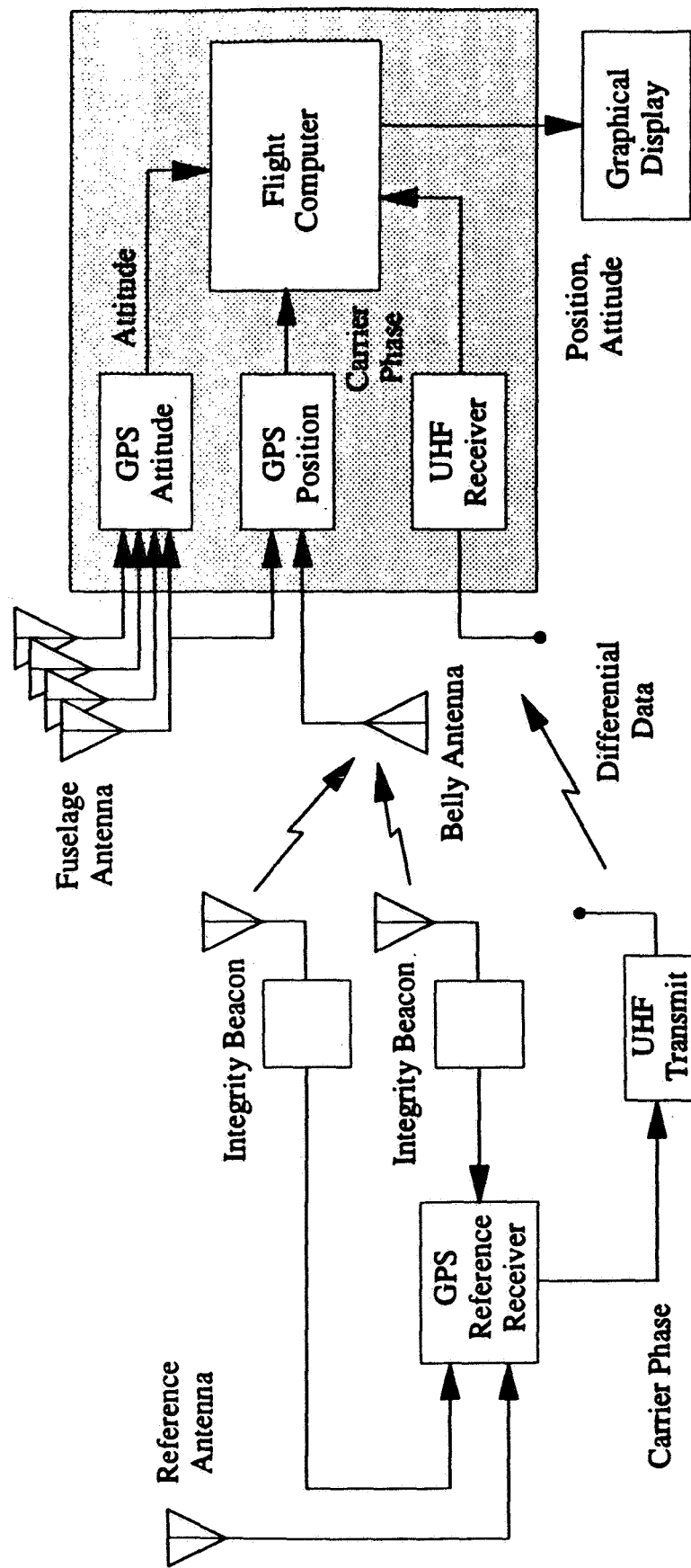
FAA Wide Area Augmentation System



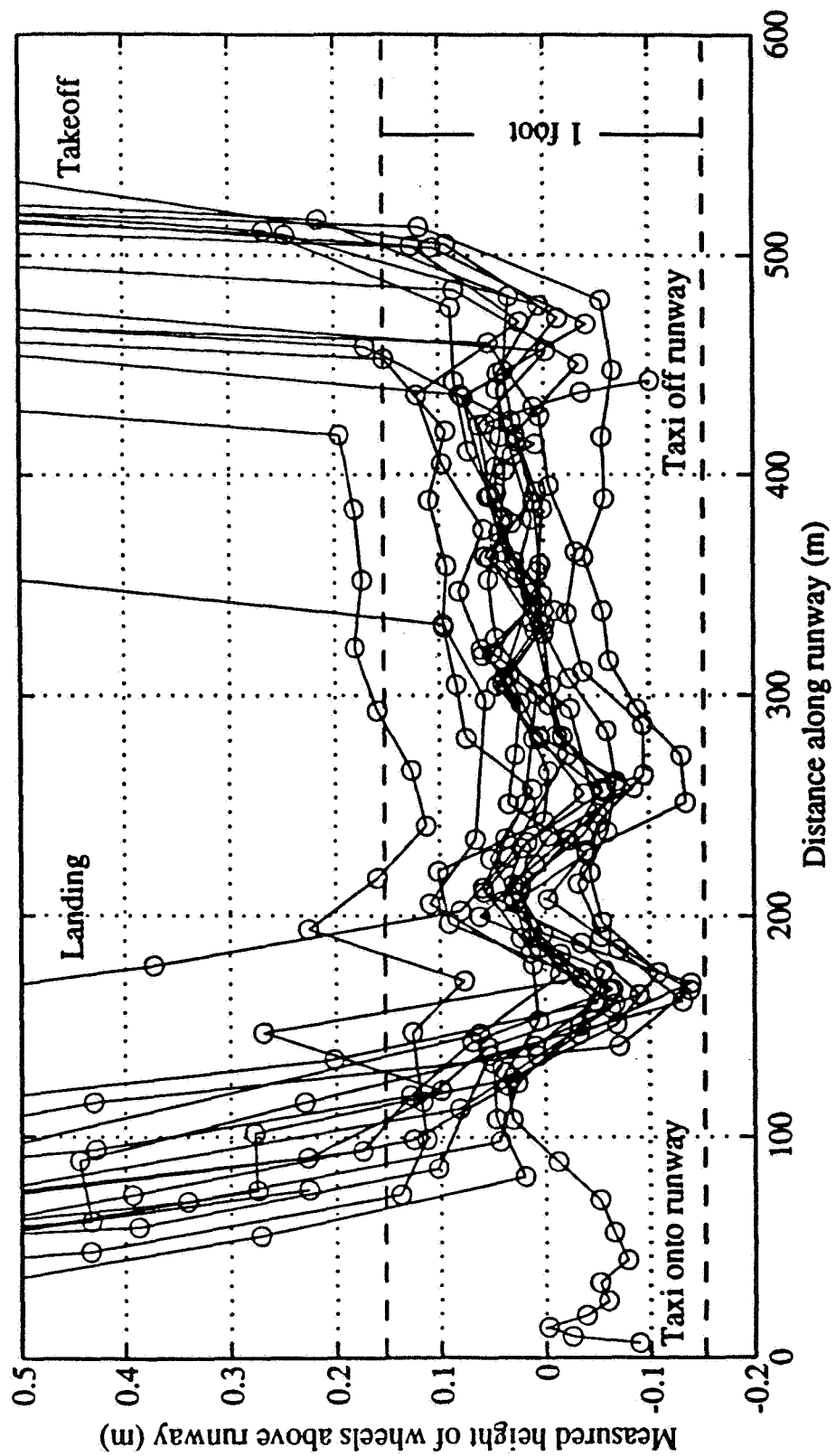
Touch and Go Landings with WAAS



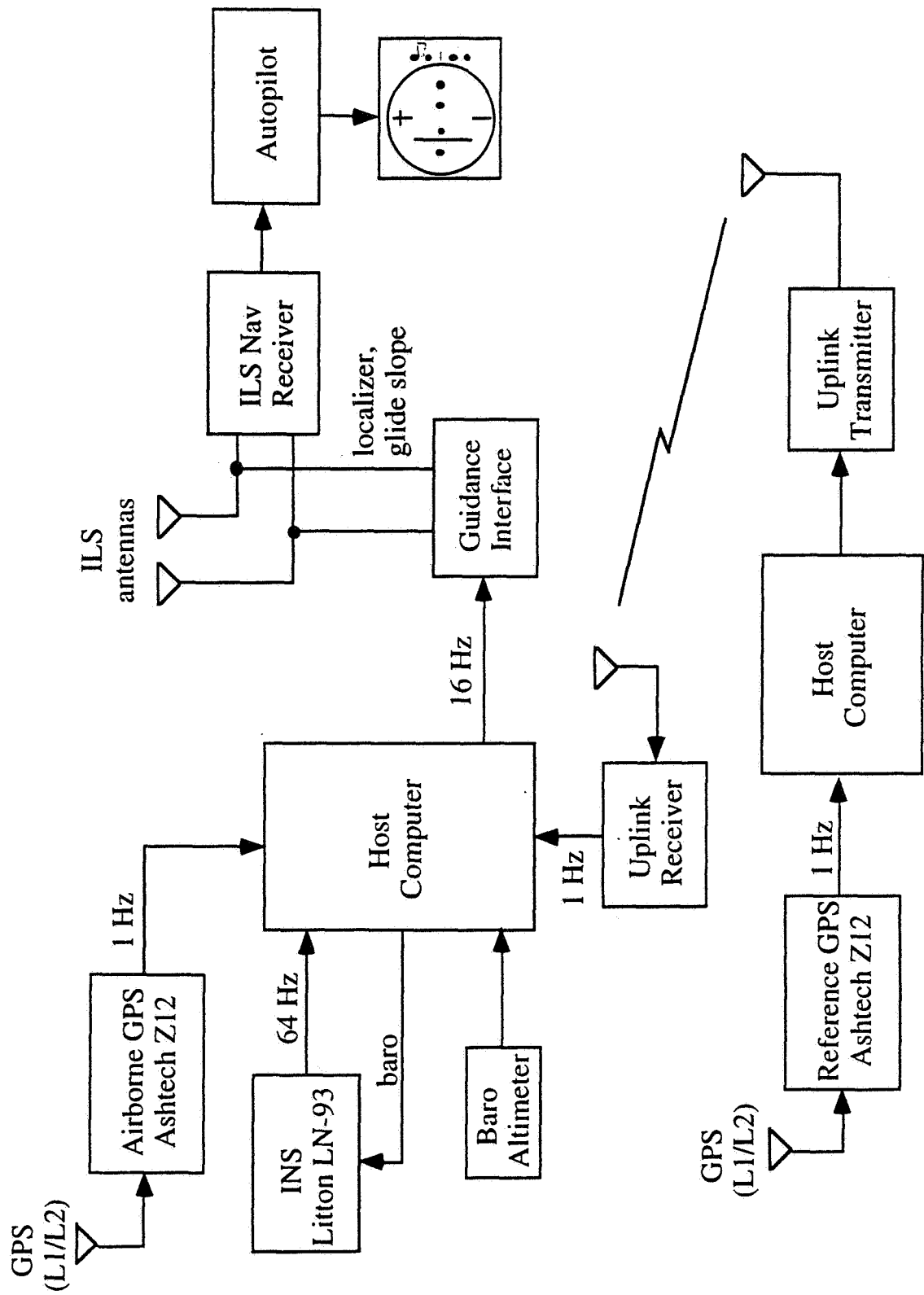
Stanford Kinematic GNSS Landing System



Touch and Go Landings with KLGs

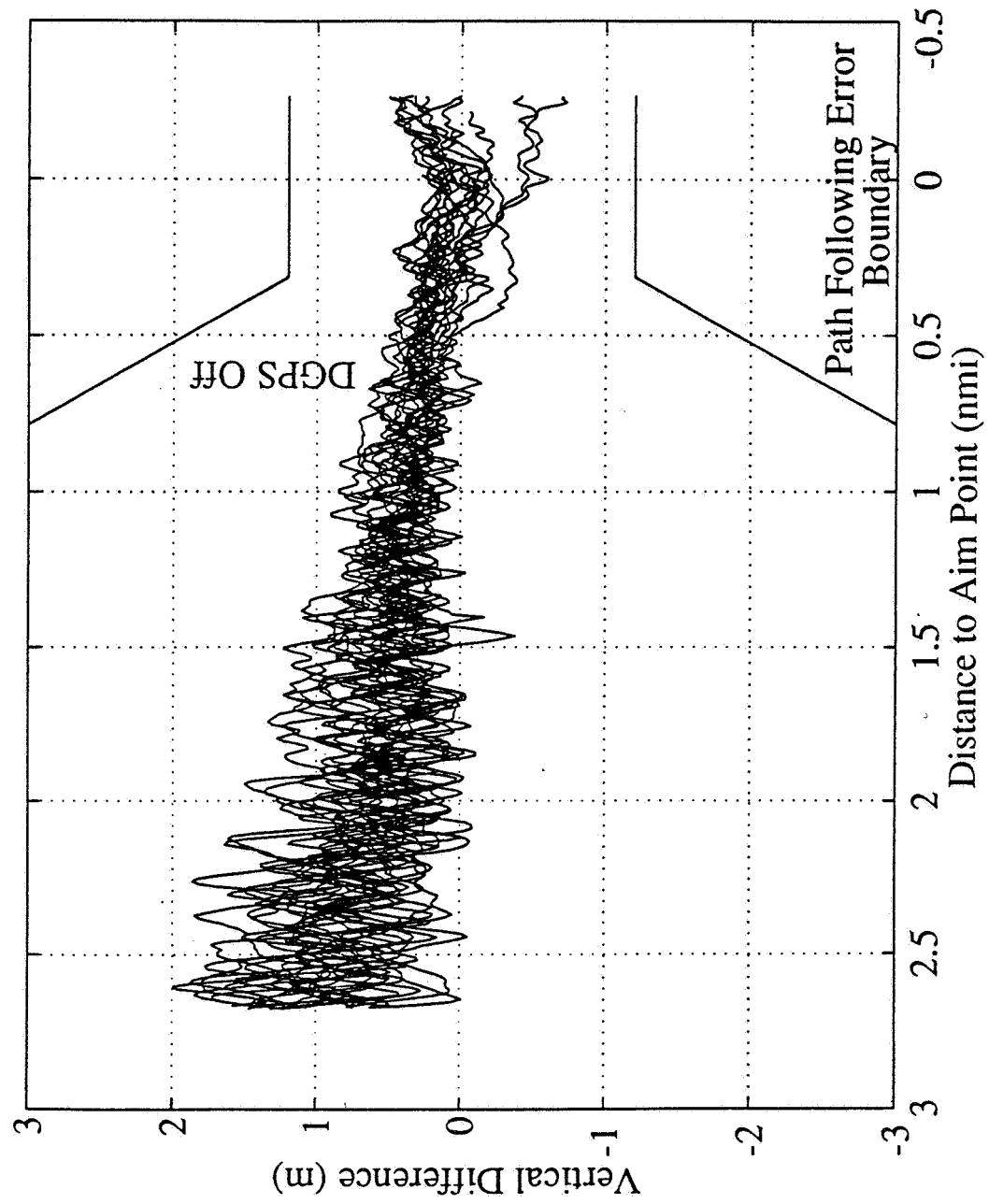


NASA Ames DGPS/INS System



Precision Approaches with DGPS Disabled at 200 ft

NASA King Air at Crows Landing, 7/21/95



Aviation Future

Air

Automatic controls
GNSS/INS guidance
Free flight navigation
Inter-aircraft communication
Automatic collision and wake avoidance
Radio control reception for emergencies

Ground

GNS integrity assurance
Rules of the sky software
Expert pilots for emergencies

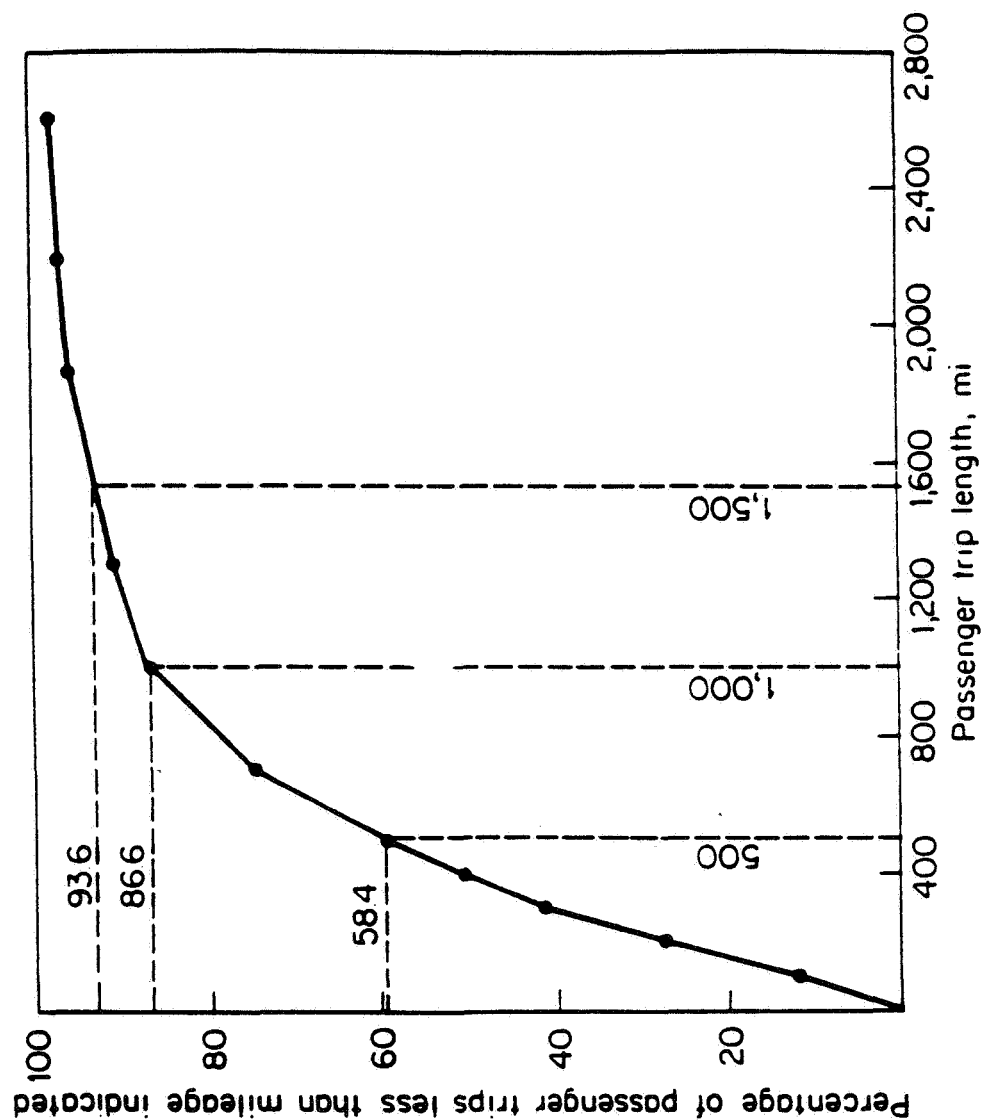
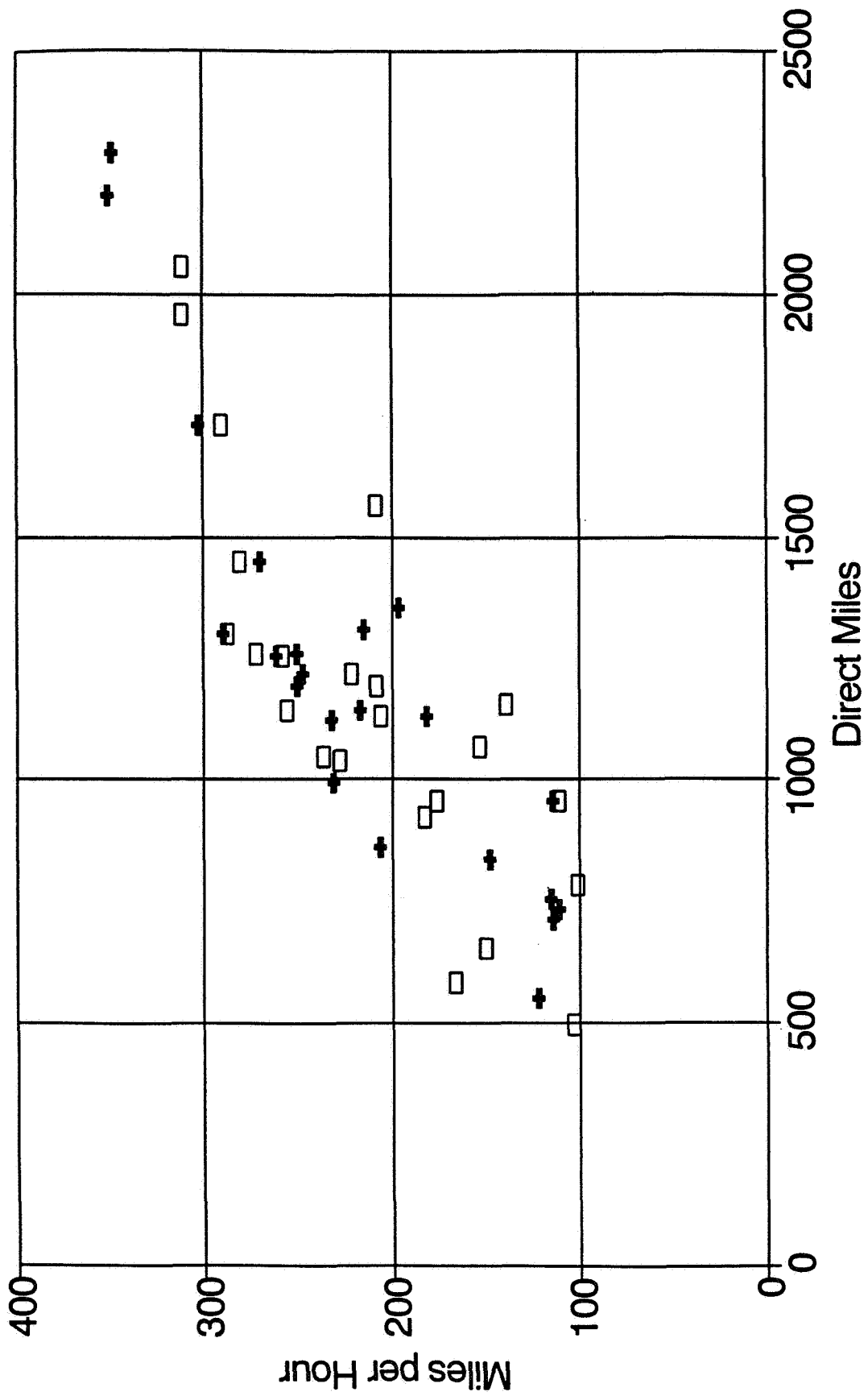


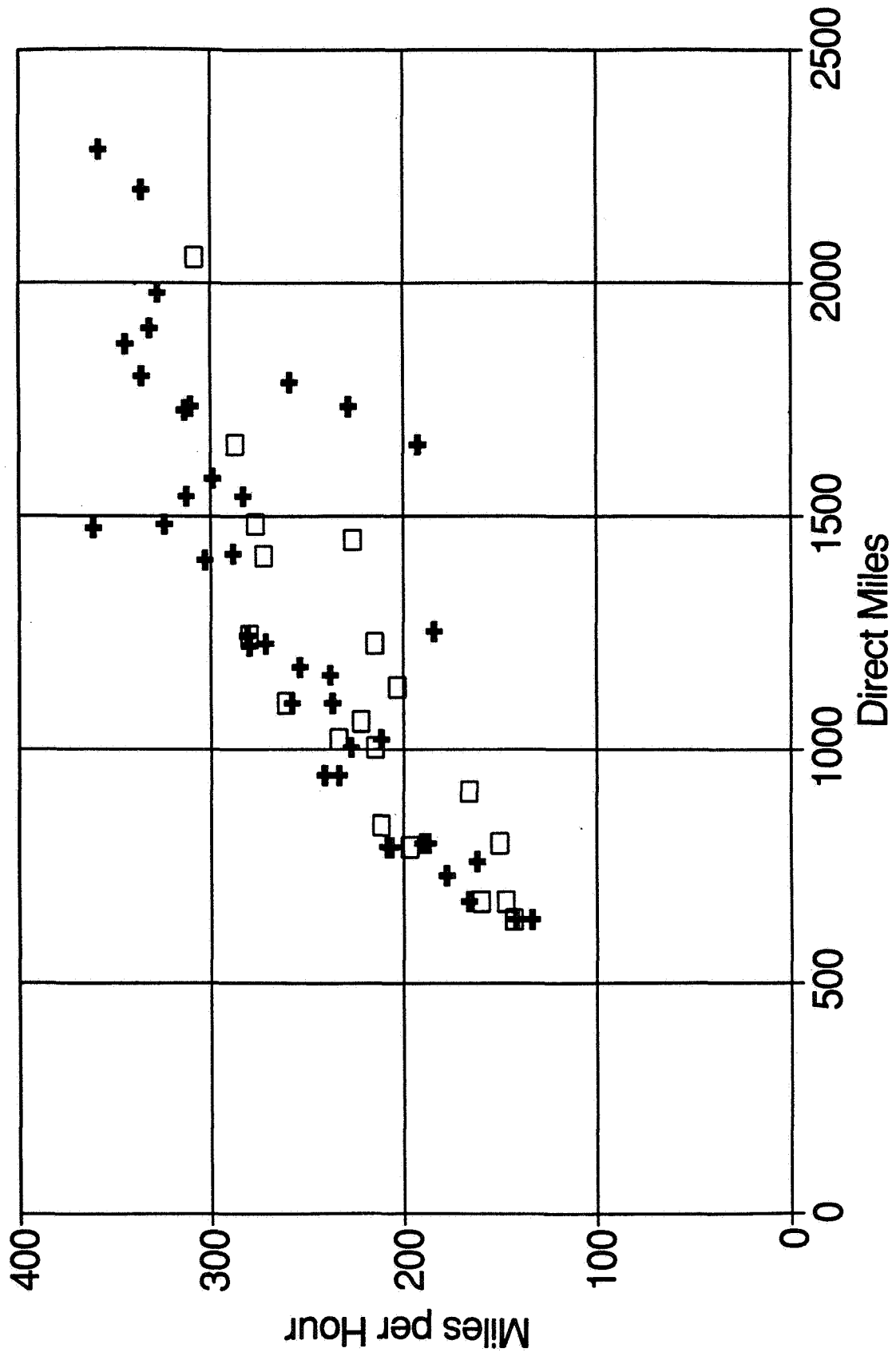
Fig. 1-1 Distribution of passenger trip lengths on scheduled domestic airline flights in the United States, November 1980. (Civil Aeronautics Board [17].)

EFFECTIVE SPEED

Tucson through Denver Hub

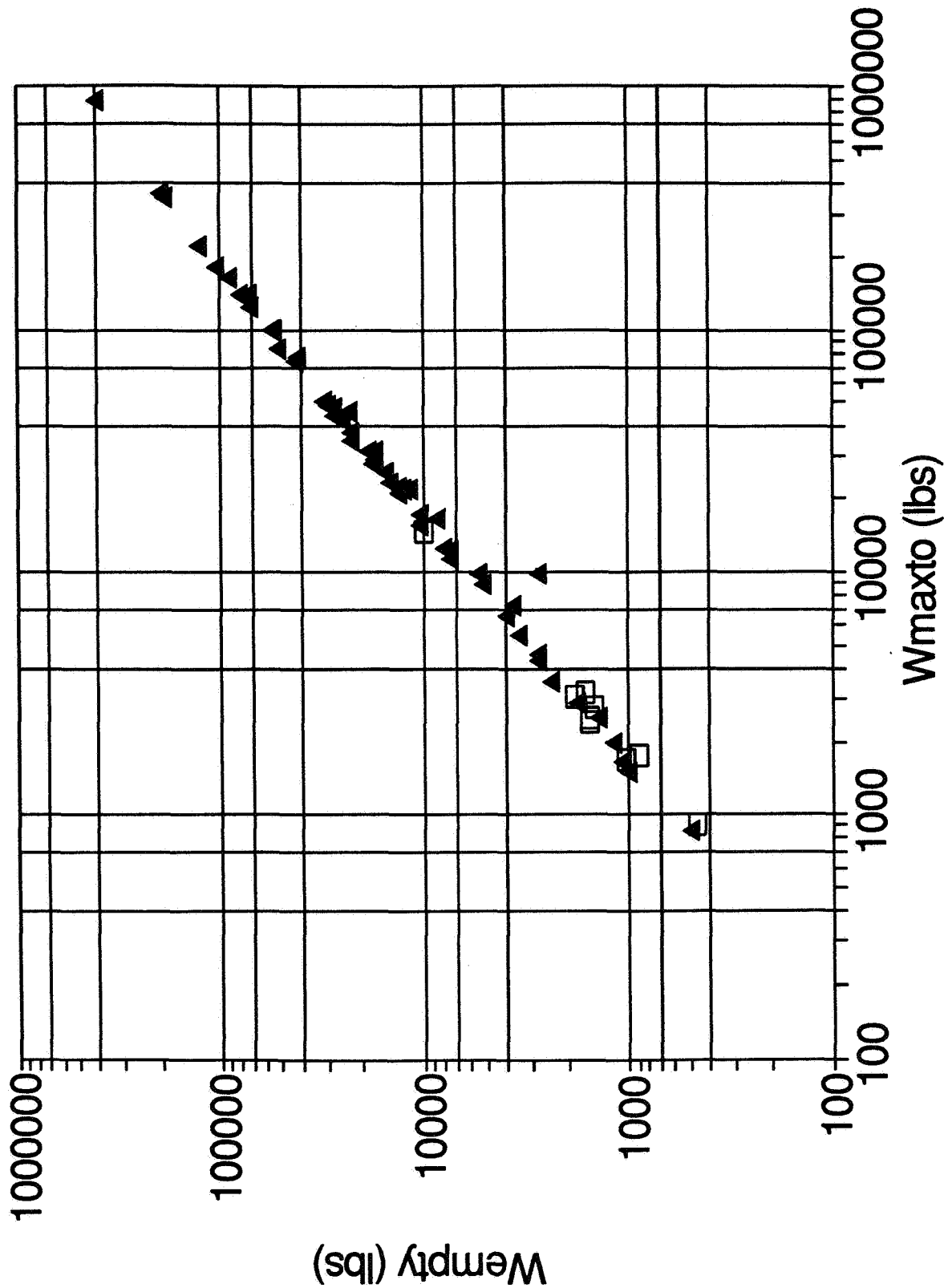


EFFECTIVE SPEED Tucson through DFW Hub



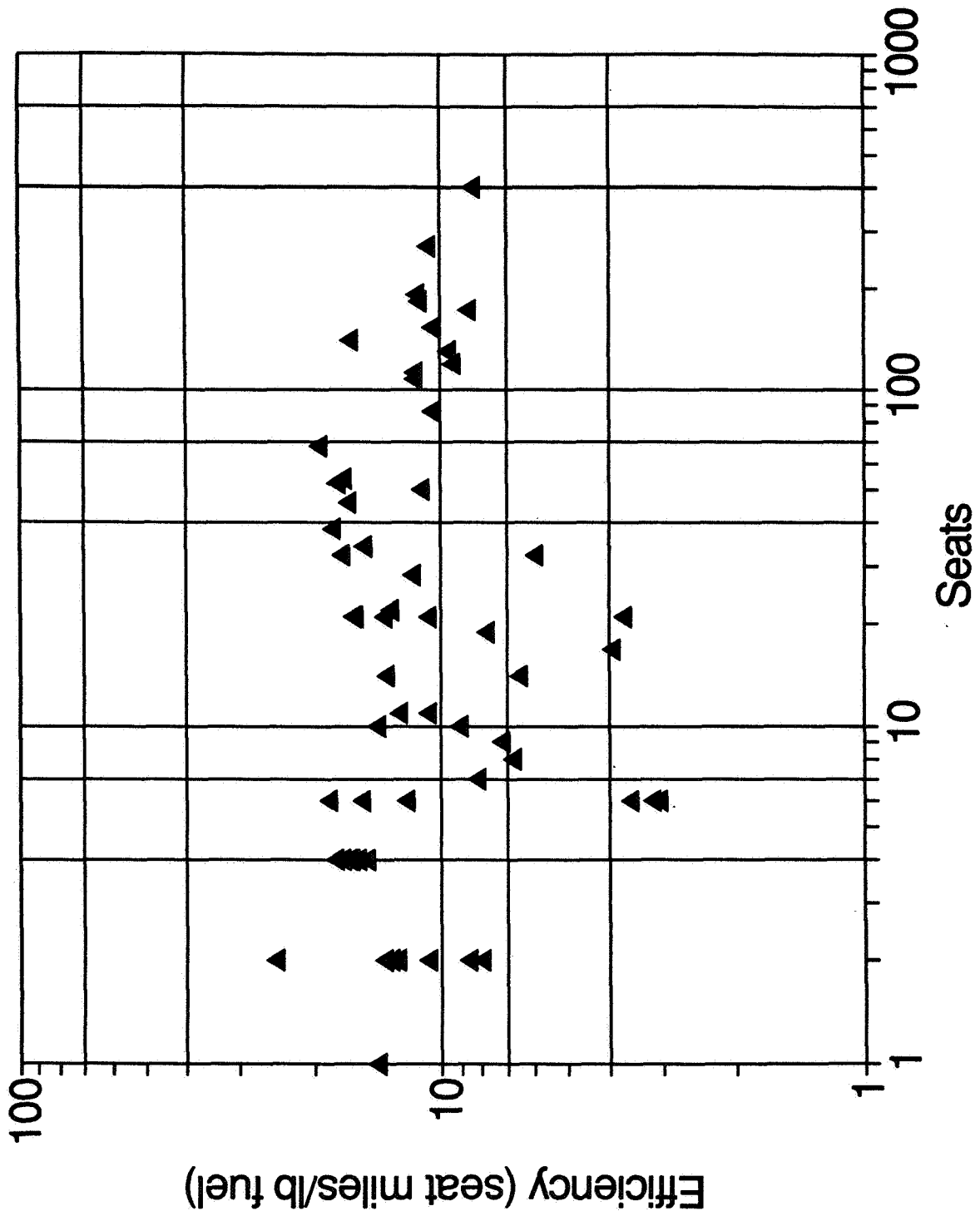
Empty Weight vs Max Takeoff Weight

$W_{empty} = 0.656 * W_{maxto} ^{0.988}$



Fuel Efficiency vs Seats

Efficiency = $11.5 * \text{Seats}^{-0.006}$



Conclusions

The information age is real and has produced machines able to process data as fast as humans and handle quantitative data much better.

The Global Positioning System allows vehicles to determine location, velocity, and attitude.

Digital telecommunications allow vehicles to communicate their states and plans among each other.

The rate gap between central processing and telecommunications will persist, so the brains of a transportation system will be aboard the vehicles.

Synthetic intelligence and telecommunications are cheap!

All this bodes well for personal aviation.

THE NEW ORGANIZATION

Rethinking Work in the Age of Virtuality

Duncan B. Sutherland, Jr.*

Memory brings forth not reality itself, which is gone forever, but the words elicited by the representation of reality, which as it disappeared impressed traces upon the mind via the agency of the senses.

—Saint Augustine, *Confessions*

Hardly anybody ever said on his or her deathbed, “I wish I had spent more time at the office.”

—William Jefferson Clinton

In a 1986 cover story, *Business Week* cataloged four decades of business fads, ranging from management by objectives in the 1950s to Theory Z in the 1980s.¹ More recently, Harvard Business School professors Robert Eccles and Nitin Nohria have noted more than *fifty* neologisms that have been added to management’s “how-to-fix-the-company” lexicon in recent years, including: *best practices*, *core competencies*, *strategic intent*, *delaying*, *informed*, *adaptive*, *post-industrial*, *borderless*, and *intrapreneurial*.² At times, the search for the “silver bullet” that will cure corporate America’s increasingly painful case of competitive dyspepsia has taken on something of the frenetic character of a quest for the Holy Grail, replete with many of the comedic qualities of the 1974 Monty Python film of the same name! From a practical point of view, however, most of the “new” management concepts that have been introduced by academics and consultants in recent decades—including concepts like

total quality management,³ *organizational architecture*,⁴ *time-based competition*,⁵ and *business re-engineering*⁶—have proved exceedingly difficult, if not impossible, for most organizations to put into practice.⁷

There are numerous reasons why these new “management tools” often fail to take hold, of course, not the least of which is that *any* new approach to management, if viewed by an organization as a panacea or quick-fix, is probably doomed to failure from the outset. Another reason is that most new management concepts, in order to be successful over the long-haul, require fundamental and often gut-wrenching changes to an organization’s culture which has proved, time and again, to be damnably difficult to achieve. However, there may be an even more fundamental reason why today’s bureaucratic organizational model doesn’t seem to work any more: the scientific paradigm or “world view” upon which it is based was never really valid in the first place.

Corporate America: Caught in the Intellectual Fly-Bottle of 19th-Century Positivist Science

The institutions that we create, whether public or private, profit or non-profit, reflect our beliefs about how the world “works.” In other words, they reflect:

1. how we interpret the various physical phenomena that we encounter on a day-to-day basis;
2. how we position ourselves relative to the force or forces that we believe to be the cause of these phenomena; and
3. what we understand to be the “natural” relationship between ourselves and other species (and, for that matter, between ourselves and others of our *own* species).

Depending on our personal inclinations, we may choose to call this broad system of beliefs “religion,” or we may choose to call it “science.” In either case,

these paradigms fundamentally shape not only how we believe the world ought to be but, far more important, how it *can* be.⁸

The foundation stones of the modern organization were laid late in the 19th century at a time when America was making the leap into the Machine Age. The prevailing scientific paradigm (belief system) of the times, based on a long history of Newtonian thinking, was thoroughly positivist in its approach to understanding the world. As cognitive scientist Jerome Bruner has noted, the “Holy Trinity” of positivist science are *reductionism*, *causal explanation*, and *prediction*.⁹ Nineteenth-century scientists, in general, and 19th-century physicists, in particular, held that the behavior of even the most complex system could be explained by a few simple laws. By understanding these laws, the future behavior of these systems could be predicted with absolute certainty. Over time, the logic of positivism was applied to virtually every field of human endeavor, from psychology¹⁰ to economics.¹¹

Positivist thinking in general, and the importance of focusing on the processes by which work was done rather than just the output of workers, in particular, was introduced to modern management with the publication of Frederick Winslow Taylor’s *The Principles of Scientific Management* in 1911.¹² Strongly influenced by the tenets of 19th-century physics, Taylor held that “[t]he best management is a true science resting upon clearly defined laws, rules, and principles as a foundation. . . . In the past the man has been first; in the future the system must be first.”¹³ In the decades since Taylor published his magnum opus, positivist thinking has become so deeply entrenched in corporate America’s psyche that it has become a metaphorical fly-bottle from which most organizations now find it virtually impossible to escape.¹⁴ Consider two recent cases in point: the nagging “problem” of white-collar productivity and corporate America’s on-going love affair with business re-engineering.

The white-collar productivity “problem” was really brought home to corporate America in the late 1970s when U.S. business magazines began reporting that the productivity growth rate of the nation’s service sector was apparently lagging far behind that of the manufacturing and agricultural sectors; particularly, when viewed from an historical perspective.¹⁵ Through some neat intellectual sleight of hand the problem was quickly re-framed by consultants and, in particular, the computer industry to one of “under-investment” in capital equipment in support of white-collar workers as compared to their counterparts in farming and manufacturing.¹⁶ The argument, while often implicit, went something like this:

1. Offices are just like modern factories, only with people rather than machines as the primary factor of production.
2. Ergo, it stands to reason that the generally accepted principles of productivity improvement that had previously worked so well in the fields and on the shop floor—principles like work rationalization and mechanization—*ought* to work just as well in the office.

Unfortunately, they didn’t. Since the 1970s, corporate America has spent hundreds of billions of dollars on technology of all kinds—including computers and even new office design concepts—in an effort to improve white-collar productivity. This is above and beyond the enormous amount of time and effort that has been expended by companies in the quest for the “magic metric” that will prove to an increasingly skeptical top management that these massive investments in technology have in fact been paying off. Nevertheless, productivity in the service sector continues to limp along and the long sought after “magic metric” has remained elusive. This debacle—and there is really no other word for it—has come to be known as the “white-collar productivity paradox.”¹⁷ Here’s how economist Steven Roach has characterized the situation:

The service sector's lagging efficiencies may seem surprising in light of the costly bet that has been wagered on the promise of computers, telecommunications, and other forms of information technology to enhance productivity. While economists have long recognized the relationship between rising capital endowment and productivity enhancement, that relationship has not been borne out in services. The massive investments in technology simply have not improved productivity; on the contrary, they have made service organizations less profitable and less prepared to compete on other fronts. . . . As a result of heavy ongoing investments in technology, the service sector's cost structure has been ominously transformed. While workers can still be hired and fired, service companies are now strapped with a steady stream of expenses to support a flourishing technology infrastructure that has taken deep root. The bottom line is that service companies have moved from a variable-cost to a fixed-cost regime, thereby sacrificing flexibility without gaining any concomitant productivity benefits.¹⁸

If anything, the "problem" of white-collar productivity has been one of management, not one of technology (or, more accurately, the lack thereof)—although some critics, and a few technology vendors, still try to argue that the latter is the case.¹⁹

As for business re-engineering, once you cut through the rhetoric and inevitable hype that surrounds business re-engineering as it is portrayed in the business press you find—surprise!—essentially the same focus on work process redesign that assumed such a prominent place in Taylor's thinking.²⁰ There *are* some major differences, of course, between Taylor's view of the world and the approaches being suggested by modern-day business re-engineering gurus. For example, Taylor did not believe that workers were capable of figuring out the most efficient way for work to be done and argued that the planning of work ought to be separated from its execution and relegated to management. Business re-engineering, on the other hand, is premised on the direct involvement of not only management, but of front-line workers and even customers as well. Nevertheless, the roots of business re-engineering, like the roots of the white-collar productivity paradox, are deeply planted in the fertile soil of 19th century positivist thinking.

There is nothing inherently wrong, of course, with trying to improve organizational processes or even trying to increase the output of white-collar workers. Continuous process improvement has always been a good idea and a company would be foolish if it didn't try to fully leverage its investment in intellectual capital. The problem is that the 19th century positivist view of management, as espoused by Taylor and others, tends to focus management's attention almost *totally* on issues related to the analysis, prediction, and control of organizations. As it turns out, however, the behavior of organizations may not only prove impossible to predict, but impossible to control, as well—at least in the sense that management tends to use these terms today.

Showing Management the Fly the Way Out of the Fly-Bottle

Scientists have recently come to understand that the behavior of many kinds of systems is fundamentally unpredictable and thus uncontrollable. This is true for certain kinds of complex natural systems like the behavior of a flock of birds in flight. It is also true for certain kinds of complex made-made systems like the stock market or, of particular interest to us, business organizations. Far from being the rational, predictable, clockwork universe of 19th-century positivist thinking, the behavior of these kinds of systems seems to be about as random as a throw of the dice. This radically new way of thinking about the world has been embodied in equally radical new theories like *chaos* and, more recently, *complexity*.²¹

Actually chaos is not a “new” theory. As noted earlier, in the 18th century Newton and his contemporaries believed that they could predict the behavior of any system if only they could identify all of its parts and the interactions between these parts. However, the impracticality, if not the sheer *impossibility*, of describing every possible interaction in a system that might have, quite literally, *zillions* of parts was realized by Sadi Carnot and his colleagues in the 19th century. Through their re-

search, though, they discovered that they could predict the statistical behavior of certain kinds of systems, so long as the parts of the systems were identical and the interactions between the parts were relatively weak. These statistical predictions became the foundation for the laws of thermodynamics.²²

It was only during the past 100 years, however, that chaos theory began to crystallize as scientists, influenced in large part by the work of Henri Poincaré, came to realize that the behavior of a system with only a few parts could, if the parts interacted strongly enough, be totally unpredictable or *chaotic*. One of the fundamental principles of chaotic systems is that even the smallest and seemingly innocuous event can have enormous and totally unpredictable future consequences. This phenomenon of small events having large and unpredictable “downstream” consequences has come to be known as the *butterfly effect*.²³ Strangely, it is chaos theory that may finally show management—albeit indirectly—the way out of the intellectual fly-bottle of 19th-century positivist thinking.

Complexity Theory, Complex-Adaptive Systems, and the New Organizational Thinking

Interest in chaos theory was renewed in the 1970s when scientists began to wonder whether the theory could account for the strange behavior of certain classes of complex systems. This line of thinking eventually led researchers to the development of *complexity theory*. Complexity theory deals with systems that lie “between” the totally predictable behavior of Newtonian systems and the totally unpredictable behavior of chaotic ones. In other words, they are systems that seem to be able to maintain themselves on the “edge” of chaos.²⁴

The basic idea behind complexity theory is pretty simple: self-organization is inevitable in a wide-range of natural and man-made systems.²⁵ Researchers working in the field of complexity theory have described these self-organizing systems as

complex-adaptive. According to complexity theory, all complex-adaptive systems—including one of the most successful complex-adaptive systems of all, the human brain—have four key characteristics in common:

1. Multiple agents. Complex-adaptive systems are made up of a network of independent “agents.” Each agent lives in a world that is a product of its interaction with other agents. As a result, virtually nothing in its environment is fixed. Control in complex-adaptive systems tends to be highly dispersed. There is no “master control center” that tells agents what to do; they are self-managing. Nevertheless, agents are capable of cooperating to produce higher-order behaviors that no single agent could produce on its own. Coherent behavior, what we would typically call “organization” in the business world, comes directly from cooperation (or even *competition*) between and among the agents themselves.

2. Building blocks. Complex-adaptive systems have many levels of organization. Agents at one level serve as “building blocks” for agents at a higher level. Most important, however, complex-adaptive systems are continually testing, rearranging, and even replacing their building blocks as they gain experience; as they *learn*. In this sense (and at a deep level), learning is fundamentally the same thing as evolution and adaptation.

3. Internal models. Every complex-adaptive system constantly makes predictions about the future based on its implicit and explicit assumptions about how things are “out there.” These models are active. They can “come to life” in a given situation, triggering situation-specific behavior. The models can be tested, refined, and rearranged as the system gains experience.

4. Perpetual novelty. Complex-adaptive systems typically occupy many behavioral (competitive) niches, with each niche being exploited by a specialized agent. A new niche opened up by a complex-adaptive system creates new opportunities for competitors, which in turn opens up new opportunities for the emergence of other adap-

tive agents, ad infinitum. Thus, new opportunities are always being created by the system. A complex-adaptive system never reaches equilibrium. It is *always* in a state of transition. If a complex-adaptive system is in equilibrium, it is dead.²⁶

These are probably unfamiliar concepts so let's briefly review the key characteristics of complex-adaptive systems:

1. **Complex-adaptive systems are self-managing.** While complex-adaptive systems are made up of independent agents, these agents are nevertheless capable of cooperating to produce higher-order behaviors that no single agent could produce on its own.
2. **Complex-adaptive systems learn.** Through feed-back from the environment, complex-adaptive systems are able to learn. Moreover, they are able to embed this learning in their physical structure. As a result, they are constantly rearranging themselves as conditions in the competitive environment change.
3. **Complex-adaptive systems operate on the principle of "flexible specialization."** Complex-adaptive systems are constantly developing new behavioral niches that are exploited by specialized agents and sloughing-off niches (and specialized agents) that are no longer useful.²⁷

If all of this is beginning to sound slightly familiar by this point, it should. It parallels *very* closely some of the "new organizational thinking" that management theorists like the Claremont Graduate School's Peter Drucker, MIT's Peter Senge, and Hitotsubashi University's Ikujiro Nonaka have been espousing. For example, Drucker notes in his now classic *Harvard Business Review* article, "The Coming of the New Organization,"²⁸ that while many details of the new organizational paradigm remain unclear, what *is* clear at this point is that the organizational model of the twenty-first century will more likely resemble a hospital, a university, a symphony orchestra, or even companies of a century ago, than the circa 1950 manufacturing company that remains the textbook norm. Drucker suggests that the new organiza-

tion will be knowledge-based and that this knowledge will reside in the minds of individual specialists who, because specialists cannot be told how to do their work, will be largely self-directing. He envisions more and more work being done in task forces that are comprised of specialists from various functions. Finally, he suggests that a major challenge for management will be to give this organization of specialists a common vision or view of the whole.²⁹

Senge, author of the management best-seller *The Fifth Discipline*,³⁰ has observed that “human beings are designed for learning.” While Senge attempts to draw a fine line between what he calls “adaptive” or *coping* learning and “generative” or *creative* learning, the bottom line of his thesis is that superior performance in an organization is *only* achievable through superior learning—adaptive or otherwise.³¹ As far as management’s role in all of this is concerned, he argues that the primary responsibility of a leader is to “define reality.”³² Senge concludes that, in a world characterized by novelty and change, a key to effective performance is the ability to create learning processes that make self-organization possible.³³

Finally, Nonaka has proposed that the only source of lasting competitive advantage is knowledge. Nonaka notes that U.S. companies, following the traditions of Western management thinking, typically view organizations as “machines for information processing.” He goes on to suggest, moreover, that these companies simply don’t understand what knowledge is nor how to manage its creation. Nonaka’s view is that new knowledge begins with the individual and is then transformed into “organizational knowledge.” It is this process of converting individual knowledge to organizational knowledge that lies at the heart of the knowledge-creating company. Nonaka, like Senge, believes that a primary role of management in such a company is to provide employees with a conceptual framework that, in his words, “helps them make sense of their own experience.” He suggests further that the concept of teams becomes increasingly important in this context because it serves as a mechanism for

fostering, through constant dialogue, the development of a new collective perspective about the world. Nonaka's bottom line is that "companies are living organisms, not machines."³⁴

Looking at organizations in this new light—i.e., as complex-adaptive systems—helps us to understand why so many companies appear to be having so much trouble adapting to what seems to be an increasingly unpredictable competitive environment. As Nonaka has stated so unequivocally, companies, far from being machines, are living systems. They are, in the most literal sense of the term, "extensions of the human mind" which, as we have seen, has proved to be one of the most successful complex-adaptive systems of all. Nevertheless, corporate America continues to try to manage white-collar organizations as if they were, in fact, machines. If companies hope to be able to survive in what promises by all accounts to be an increasingly chaotic and complex world,³⁵ this kind of 19th-century positivist thinking must change and it must change *fast*. Perhaps the best place to initiate the change process is to reassess some of our most deeply held beliefs about the nature of the modern business organization.

Organizations Viewed as Complex-Adaptive Systems

Complexity researchers, along with theorists from a number of other disciplines from law to the environment, have begun to look at man-made systems like the economy,³⁶ the emergence of high-tech companies,³⁷ and even urban planning.³⁸ However, the concepts of complexity theory, such as the notion of complex-adaptive systems, have yet to be translated in any concrete way to the world of business organizations. Nevertheless, a number of implications that would flow from such a fundamental paradigm shift are becoming obvious. In particular, the critical importance of *individual learning*, the concept of *cooperative management*, and the notion of *continuous organization* promise to *fundamentally* change the ways in which organizations go

about planning, designing, and managing the technology infrastructures that enable their intellectual capital.³⁹ Let's consider each of these implications in more detail.

1. Individual learning. As complex-adaptive systems, business organizations are able to achieve sustainable competitive advantage *solely* through the learning of agent-individuals; the sharing of this learning with other agent-individuals; and, ultimately, the embedding of this learning in the organization's physical structure. The term "learning organization" is an oxymoron. Organizations don't learn, *agent-individuals* do. An enterprise that focuses on organizational learning is, as the saying goes, putting the emphasis on the wrong "syl-la'-ble!"

2. Cooperative management. As complex-adaptive systems, business organizations consist *only* of independent, self-managing agent-individuals. Even when we think that agent-individuals are being "managed" they are, in reality, still acting on the basis of their own individual intentionality. As a result, their behavior is not totally predictable as the 19th-century mechanistic view of organizations would lead one to believe. In effect, "management" (in the sense of *control*) is a myth. Any collective intentionality that seems to be exhibited by an organization is simply the result of cooperation or competition between independent, self-managing agent-individuals.

3. Continuous organization. As complex-adaptive systems, business organizations must *always* be in a state of transition—or they are, quite literally, dead. Change is a natural state of affairs as the organization continuously embeds the learning of its agent-individuals in its physical structure and continuously acquires and sloughs-off specialized agent-cooperatives in response to the changing demands of the competitive environment. Nevertheless, most companies tend to view themselves as going through relatively long periods of organizational stability punctuated by brief bursts of change they call "reorganization"—or at least this is their goal based on the misguided belief that there is a "correct" organizational model if it can only be

“discovered.” However, the reality is that a state of continuous organization is the *norm* for a business enterprise rather than the exception.

Let’s now consider how each of the implications we derived from viewing companies as complex-adaptive systems consisting of self-managing agent-individuals and agent-cooperatives—individual learning, cooperative management, and continuous organization—is likely to impact the way in which an organization approaches the planning, design, and management of the technology infrastructure that supports its intellectual capital.

Individual Learning

As we have seen, complex-adaptive systems are *learning* systems. Because agent-individuals learn and not organizations, the primary function of an organization’s technology infrastructure must be to help enable agent-individual learning while, at the same time, enabling the *sharing* of this learning on a continuous (and more often than not *informal*) basis with other agent-individuals. Unfortunately, this is not a simple thing to do. Human beings tend to be *highly* idiosyncratic with respect to *when, in what kinds of physical settings, and with what kinds of sensory stimulation* they feel they do their “mind’s best work.”⁴⁰ For example, Ben Franklin and Victor Hugo, two towering historical figures, believed that they did their best thinking *au naturel*.⁴¹ Martin Luther claimed to have had his holiest moments while sitting on the privy.⁴² Dame Edith Sitwell used to lie in a coffin for a few hours before she began her day’s writing.⁴³ Charles Dickens had to position his furniture in exactly the right way before he could begin to work, going so far as to totally rearrange the furniture in hotel rooms or rented spaces where he wrote.⁴⁴ And the German poet Johann von Schiller used to keep rotting apples in his desk and inhaled their pungent odor whenever he was stuck for just the right word.⁴⁵

On a more contemporary note, “Doonesbury” creator Gary Trudeau believes that he does his best creative thinking in the hot shower.⁴⁶ Cray Research founder Seymour Cray admitted that he dug tunnels in his backyard when he was stuck on a particularly thorny engineering problem.⁴⁷ Noted designer Michael Vanderbyl has found that he likes designing while flying from place to place on commercial airliners.⁴⁸ And, as anyone who has had teenagers around the house can attest to, the best possible setting for homework is flopped over a chair with the television on and the volume cranked-up, with rock music blasting through a set of headphones, while simultaneously talking with friends (preferably of the opposite sex, of course) on the telephone.

Some of the foregoing examples may seem a bit, well, *extreme*. It would probably *not* be a good idea to suggest to top management that everyone run around the office naked, keep rotting apples next to their PCs, or spend more time than they already do in the john. Nevertheless, there is a growing body of evidence, both anecdotal and scientific, that the human mind may well have an innate need to seek-out sensory delight or *pleasure* in the context of doing its best work. In other words, the ability to effectuate *ad hoc* changes in one’s sensory environment may be inextricably tied to one’s ability to fuel creativity, break through mental log jams, or simply to think great thoughts.⁴⁹

Should this really surprise us? Researchers continue to substantiate what common sense has already taught us by discovering crucial links between senses like vision, touch, smell, and sound, and cognitive abilities like memory. These links are critical both during the brain’s formative years as well as throughout life.⁵⁰ And, as Michael Schrage reminds us, a conversation that we might have over the dinner table is very likely to be *qualitatively* different from the same conversation that we might have across a desk or a conference table.⁵¹ In fact, some of the most effective client meetings I have ever participated-in took place while I was with the London-based

design firm FITCH, plc's Exploratory Design Lab. Sometimes, these meetings took the form of informal dinners at co-workers' homes with everyone, clients included, participating in the preparation as well as the partaking of the meal. At other times, they involved nothing more sophisticated than sharing a simple picnic lunch with clients at tables set up next to a farm pond on the firm's Worthington, Ohio, campus.⁵² The point is that, as Schrage suggests, in each of the examples cited the settings contributed *immeasurably* to the quality of the conversations.

We could go even further, of course. The quality of discussions held while sprawled out on a stairway or in an impromptu "conference room" constructed by moving a table, some chairs, and sheets of foam board out onto a deck on a beautiful summer day, are likely to be qualitatively different from the same discussion held in a traditional conference room—and *certainly* qualitatively different from the same "discussion" held in a space designed to support so-called "computer-supported collaborative work."

With respect to the sharing of individual learning with others, Senge has suggested that the most effective way to accomplish this is through *dialogue*—from the Greek *dia-logos* which Senge interprets to mean "the free flowing of meaning through a group, allowing the group to discover insights not attainable individually."⁵³ This suggests a much *richer* and, almost certainly, much more *informal* communication environment than is typically found in most organizations today, where much of what passes for "communication" does so in the form of mandated one-page memos or interminable voice mail messages.⁵⁴

The bottom line is that, if the goal is to help enable agent-individual learning and the sharing of this learning with other agent-individuals, then organizations must allow, and even *encourage*, the use of the widest possible range of work settings by its employees. This will almost certainly include work settings that are not tech-

nically “part” of the firm. For example, homes, neighborhood parks, local beaches, or perhaps even a local coffee house.⁵⁵

Likewise, an organization must be flexible in terms of *when* and not just *where* “work” takes place. Common sense alone tells us that the human mind does not necessarily do its best work, on demand, between the hours of 8:00 a.m. and 5:00 p.m. Some people do their best intellectual work early in the morning while others do theirs late at night. Work *does* need to be coordinated, of course, but with today’s technology this does *not* necessarily carry with it the need for spatial or even temporal co-location of those who must do the coordinating. Rather than starting with the premise that *everyone* needs to be “at work,” management should start with the premise that *nobody* needs to be “at work,” and then work backwards from there. As FI Group⁵⁶ and Chiat-Day⁵⁷ have discovered, the results might be rather surprising.

Based on the foregoing discussion, we can begin to develop some “first principles” with respect to how a company *ought* to approach the planning, design, and management of a technology infrastructure that enables learning, both from the perspective of agent-individuals and as a shared or “organizational” experience:

1. It is both unreasonable and unrealistic to expect people to work with highly sophisticated tools “in the office,” like advanced computer and telecommunication systems and specialized facilities, but with only marginally useful tools “at home.” In even the recent past, this would have meant duplicating rather expensive tools “at work” and in one or more alternative work settings. Today, however, with the advent of increasingly powerful notebook computers and advanced communication technology, it is becoming quite feasible for an individual to have a true *personal* computer that she uses in the office, while traveling, and at home. Of course, this means that company assets “walk out the door” every evening and this causes traditional technology managers

many sleepless nights wondering whether people will lose them, break them, or perhaps use them for “non-business purposes.”⁵⁸

2. A company’s facilities should, insofar as possible, be designed to make available the broadest possible range of sensory delight to its workers including sights, smells, sounds, and so forth. This would certainly include the ability to work out-of-doors, should one choose to do so, on a brisk autumn day. In northern climes, it might also include the ability to meet with customers in front of a roaring fire on a cold winter’s day; a perk that has, of course, traditionally been jealously guarded by top management.⁵⁹ Obviously, this kind of thinking has some interesting implications such as the necessity of providing connectivity and power to such non-traditional work settings as decks, stairways, and even “remote” locations like the picnic tables mentioned earlier. Who knows where an individual or a task force might want to “work?” In all cases, of course, the data and communication networks must be self-configuring so that workers can literally “plug-and-play.”
3. The technology infrastructure should be designed to allow individuals and teams to create their own intellectually supportive work settings. The idea here is to provide a “kit of parts,” along with the requisite education and technical support to keep them out of real trouble (and to deal with practical matters like building codes, fire codes, etc.), that allows the self-crafting of work settings that the individuals and task forces that use them *believe* support the particular intellectual task at hand. Again, within FITCH’s Exploratory Design Lab, individuals and teams were not only able to design their own work settings, but were even encouraged to bring pieces of particularly meaningful personal furniture into the office. As an experiment, people were at one

point even given small budgets to buy idiosyncratic furniture. This is *clearly* not a strategy that will win many design awards and it certainly gives the “bean counters” (and the facility managers) fits. However, it has one over-riding redeeming feature: it *works*.⁶⁰

Self-Managing Organizations

Probably the most significant implication with respect to the planning, design, and management of a technology infrastructure given an organizational paradigm in which virtually the entire company consists of self-managing agent-individuals and agent-cooperatives, aside from the fact, of course, that they can’t really be “managed” in the traditional sense of the word, lies in how these agent-individuals and agent-cooperatives are likely to be dispersed in time and space.

In the first place, people who are true specialists (which, as Drucker notes, companies will need in order to be able to compete in the future) are not always easy to *find*, let alone *keep*. Moreover, they do not always *want* to work in the city in which the company that wants to hire them is located. Even when they are located in the same city, they do not always *want* to, nor are they always *able* to, come to “the office.” This suggests, of course, that such organizations are likely to be *much* more widely distributed with respect to time and space than the organizations we know today.

This is not a new idea, of course; it is just new to most companies. In the early 1960s, Steve Shirley was refused maternity leave from her then employer, British computer-giant ICL. The result was that she quit ICL and formed what may well have been the world’s first “virtual” consulting firm, F International (now FI Group, a £25 million company with an enviable list of clients ranging from Unilever to British Telecom). Early-on, every employee of the firm, including Shirley, worked either out of their homes or at client sites.⁶¹ While the firm has more re-

cently added some “work centers” to its technology infrastructure, the original model in which the firm’s employees work primarily at home or at client sites remains largely intact.⁶²

More recently, the advertising giant Chiat-Day has also decided to go “officeless.” According to company chairman Jay Chiat, the firm will shortly become the first “virtual ad agency” with employees working either out of their homes or out of client’s offices rather than out of “company” offices (although, like the FI Group, Chiat-Day does intend to maintain a few meeting rooms and study carrels for work that really *can’t* be done anywhere else).⁶³

How *does* a company that is widely distributed in time and space ensure that the learning acquired by agent-individuals is shared with the rest of the organization? Technology can certainly play an important role in this regard. This has been amply demonstrated by Xerox’s “Colab” research at the company’s Palo Alto Research Center (Xerox PARC)⁶⁴ as well as by the experience of teleworkers at companies like American Express and Aetna.⁶⁵ However, when the goal is to enable *dialogue* (using the term in Senge’s highly connotative sense that implies much more than swapping voice mail messages), there is as yet no technological substitute for face-to-face conversation in a setting that allows the participants to take intellectual advantage of the full sensory richness of the moment. An interesting approach to addressing this issue has been adopted by FI Group which has introduced the rather novel idea of “flying squads” as a way of helping to enable the on-going transference of learning throughout the officeless organization. Flying squads are members of FI Group’s core team. They are individuals who move from project to project, spending perhaps several weeks to a month or more “assisting” the project team, and whose function is to capture and codify the “know-how” that has been acquired by individual team members.⁶⁶

It is important to always keep in mind, of course, that the word “technology,” as we are using it in this context, encompasses both tools *and* the culture in which the tools are embedded. Thus, FI Group’s flying squads would be as much a part of the company’s technology infrastructure as would Xerox PARC’s technology-based Colab.

Continuous Organization

As noted above, most companies tend to view themselves as going through relatively long periods of organizational stability punctuated by brief bursts of change called “reorganization.” In fact, today’s approaches to technology infrastructure planning, design, and management are fine-tuned to this kind of organizational dynamic. The premise behind this kind of thinking, of course, is that there is a “right” way to organize if a company can only find it. In the meantime, however, everyone plays musical chairs and the entire organization is distracted from its real role in life: *individual learning and the sharing of this learning with others.*

As we have seen, however, complex-adaptive systems are in a constant state of transition that results from the continuous embedding of learning in their physical structure and the continuous creation and sloughing-off of competitive niches occupied by agent-individuals or agent-cooperatives. Thus, rather than being characterized by periods of relative stability punctuated by short periods of change, complex-adaptive systems, including business organizations, are really in a state of *continuous organization*. In the case of business organizations, however, they just don’t know it. Most of them still think that Taylor was right.

The notion of continuous organization carries with it the implication of a flexible and *very* robust technology infrastructure that is capable of supporting, quite literally, moment-by-moment change in the work settings it enables. This change, moreover, must be able to be carried-out directly and in real time by non-technical

agent-individuals. This means that a company's white-collar workers must become "designers" of the work settings that ultimately enable their minds' best work. This may seem absurd on the face of it. After all, companies don't pay white-collar workers to be designers of work settings (unless, of course, like architects or facility managers, they have been hired specifically to do this kind of work). Nevertheless, as counter-intuitive as it may seem, it is entirely consistent with Senge's view of one of management's most important roles in the learning organization: "leader as designer."⁶⁷ We are simply extending the concept of leader a bit to encompass *everyone* in the organization. We are able to do this because, in a complex-adaptive system which is made up of self-managing agents, everyone (and, at the same time, of course, *no one*) is a "leader."

Looking Ahead

Several open issues remain. For example, what will happen to all of the people who *currently* plan, design, and manage corporate America's technology infrastructures? It is entirely possible—and perhaps even highly *probable*—that the role of the technology manager as we know it today will be subsumed by a new role that represents a melding of several existing (and traditional) functions including: information systems; telecommunications; facilities management; and possibly even human resources. One niche that this new "specialized agent" would occupy, of course, would be the planning, design, and management of the technology infrastructure itself. In other words, the tools, and the *embedding culture* that surrounds their use, and which enables other non-technical agent-individuals to craft work settings that, in turn, enable the learning and concomitant continuous organization required of a complex-adaptive system. However, this specialized agent would occupy another niche, as well: educating and supporting other agent-individuals in the use of the technology infrastructure that enables them to do their mind's best work. In other words, using tools

to help enable individual learning. After all, that's what complex-adaptive systems are all about.

From the point of view of technology vendors, the major challenge will be to design tools that are capable of being manipulated directly by non-technical agent-individuals. This is in sharp contrast to the way this is typically done today, of course, where tools are often designed to be manipulated *only* by technicians.

Last, but certainly not least, the major challenge for management will be to escape from the intellectual fly-bottle of 19th-century positivist thinking in the first place. It is really *hard* to think about a totally new organizational paradigm like the one we have been discussing.

It is fun and certainly intellectually challenging to read Drucker, Senge and Nonaka, and then try to imagine how *we* might work in—or even run—a company like they describe. Of course, “reality” quickly sets in and we drift back to business as usual. As we have seen, however, the “reality” in terms of how companies try to organize themselves today, including how they currently plan, design and manage the technology infrastructure that supports learning, is *far* from natural. As noted earlier, Watzlawick has observed (and Saint Augustine before him!) that each of us *invents* our own version of reality.⁶⁸ The challenge facing corporate America, then, will be to invent a version of organizational reality—including throwing out much of our conventional management wisdom with respect to “systems”—that will *work* in a world that promises only to be more chaotic, more complex, and less predictable as we proceed to leap into the third millennium.

It is clear that the future competitive advantage of American companies will increasingly depend upon their ability to fully leverage their intellectual capital—their “creative sparks” as *Fortune* has characterized it.⁶⁹ Management will be left with no option but to fundamentally rethink current approaches to both managing, and technologically enabling, their most important (and most *expensive*) asset. Com-

panies that do not fully appreciate the implications of understanding organizations as non-Newtonian phenomena are likely to find themselves at a significant competitive disadvantage—or worse.

Notes

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¹J.A. Byrne, "Business Fads: What's In—and Out," *Business Week*, 20 January 1986, pp. 52–61.

²R.G. Eccles and N. Nohria, *Beyond the Hype: Rediscovering the Essence of Management* (Boston: Harvard Business School Press, 1992), p. 1.

³See, for example, A. Feigenbaum, "Total Quality Control," *Harvard Business Review*, November–December 1956, pp. 93–101.

⁴See, for example, D.A. Nadler, M. Gernstein, et al., *Organizational Architecture: Designs for Changing Organizations* (San Francisco: Jossey-Bass Publishers, 1992).

⁵See, for example, G. Stalk Jr. and T.M. Hout, *Competing Against Time: How Time-based Competition is Reshaping Global Markets* (New York: The Free Press, 1990). But compare: T. Peters, "Time-Obsessed Competition," *Management Review*, September 1990, pp. 16–21.

⁶See, for example, M. Hammer and J. Champy, *Reengineering the Corporation: A Manifesto for Business Revolution* (New York: Harper Business, 1993).

⁷J. Case, "Why 'Fixes' Fail," review of *American Business and the Quick Fix*, by M.E. McGill, Inc., January 1989, pp. 25–26.

⁸See, for example, T.S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: The University of Chicago Press, 1970). See also: D. Goleman, *Vital Lies, Simple Truths: The Psychology of Self-deception* (New York: Simon & Schuster, 1985); and P. Watzlawick, *The Invented Reality: How Do We Know What We Believe We Know?* (New York: W. W. Norton & Company, 1984).

⁹J. Bruner, *Acts of Meaning* (Cambridge: Harvard University Press, 1990), p. xiii.

¹⁰D.H. Freedman, "Is Management Still a Science?," *Harvard Business Review*, November–December 1992, p. 30.

¹¹C.R. Morris, "It's Not the Economy, Stupid," *Atlantic Monthly*, July 1993, p. 51.

¹²F.W. Taylor, *The Principles of Scientific Management* (New York: W. W. Norton, 1911, 1947).

¹³Quoted in Freedman, "Science?," p. 27.

¹⁴Watzlawick, *Reality*, p. 249. A cognitive psychologist, Watzlawick draws upon a metaphor he attributes to Ludwig Wittgenstein—"What is your aim in philosophy?—To show the fly the way out of the fly-bottle."—to explain how people tend to get themselves caught-up in seemingly inescapable intellectual traps. As explained by Watzlawick:

Old fashioned fly-bottles had a funnel-like opening whose large outer mouth made it appear safe for the fly to venture into the excitingly smelly (but gradually narrowing) interior. Once inside the inner chamber, the only way back out was through the same narrow inner opening of the funnel through which the fly had entered. But seen from the inside, this hole now appeared even more confining and dangerous than the chamber in which it found itself caught. Following Wittgenstein's metaphor, it would now be necessary to convince the fly that the only solution to its dilemma was the seemingly least likely and most threatening one. Ibid.

¹⁵See, for example, "Publisher's Memo," *Business Week*, 14 May 1979, p. 6.

¹⁶See, for example, C. Byron, "Now the Office of Tomorrow," *Time*, 17 November 1980, p. 80. Byron observes that:

Each American farmer works with an average of \$52,000 worth of such labor-saving machinery as tractors, combines and milking machines. The average American factory worker is supported by about \$25,000 in capital investment in everything from computerized assembly lines to forklifts. Office workers, on the other hand, are aided by a paltry \$2,000 in capital investment Ibid.

¹⁷P.A. David, *Computer and Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror*, Stanford University Center for Economic Policy Research Publication Series, no. 172 (Stanford: Stanford University Center for Economic Policy, 1989). See also: D.B. Sutherland Jr., "Technology and the White-collar Productivity Paradox: Time, Tools, and the Mind's Best Work," in *Productivity in Knowledge-Intensive Organizations: Integrating the Physical, Social, and Informational Environments*, edited by H.V.D. Parunak (Ann Arbor, Mich.: Industrial Technology Institute, 1992).

¹⁸S.S. Roach, "Services Under Siege—The Restructuring Imperative," *Harvard Business Review*, September–October 1991, p. 85.

¹⁹See, for example, Wang Laboratories Inc., 1992 *Third Quarter Report* (Lowell, Mass.) in which the company asserts that: "Office productivity, in the opinion of many experts, is the number one information technology issue for the 1990s."

²⁰T.A. Stewart, "Reengineering: The Hot New Managing Tool," *Fortune*, 23 August 1993, pp. 40–48.

²¹See, for example, J. Gleick, *Chaos: Making a New Science* (New York: Viking, 1987); R. Lewin, *Complexity: Life at the Edge of Chaos* (New York: Macmillan Publishing Company, 1992); and M. M. Waldrop, *Complexity: The Emerging Science at the Edge of Order and Chaos* (New York: Simon & Schuster, 1992).

²²R. Ruthen, "Adapting to Complexity," *Scientific American*, January 1993, pp. 131–132.

²³The "butterfly effect" is so-named because, in a chaotic system like the weather, a butterfly flapping its wings in Tokyo could, theoretically at least, cause an atmospheric perturbation that eventually results in a thunderstorm in New York City.

²⁴Ruthen, "Adapting," p. 132. See also: Lewin, *Complexity*; and Waldrop, *Complexity*.

²⁵M.D. Lemonick, "Life, the Universe and Everything," *Time*, 22 February 1993, p. 62.

²⁶Waldrop, *Complexity*, pp. 145–147.

²⁷Freedman, "Science?," p. 32.

²⁸P.F. Drucker, "The Coming of the New Organization," *Harvard Business Review*, January–February 1988, pp. 45–53.

²⁹*Ibid.*, pp. 45–51.

³⁰P.M. Senge, *The Fifth Discipline: The Art and Practice of a Learning Organization* (New York: Doubleday/Currency, 1990).

³¹P.M. Senge, "The Leader's New Work: Building Learning Organizations," *Sloan Management Review*, Fall 1990, pp. 7–8.

³²*Ibid.*, 11. Here Senge is quoting retired Herman Miller CEO Max de Pree.

³³Senge, *Discipline*, p. 345.

³⁴I. Nonaka, "The Knowledge-Creating Company," *Harvard Business Review*, November–December 1991, pp. 96–104. See also: W.R. Scott, *Organizations: Rational, Natural, and Open Systems* (New York: Prentice Hall, 1992).

³⁵See, for example, C. Handy, *The Age of Unreason* (Boston: Harvard Business School Press, 1989).

³⁶See, for example, Freedman, "Sciences?," p. 32; Lemonick, "Life," p. 63; and Waldrop, *Complexity*, pp. 93–96.

³⁷See, for example, Ruthen, "Adapting," pp. 133–34.

³⁸See, for example, R.J. Cartwright, "Planning and Chaos Theory," *Journal of the American Planning Association*, winter 1991, pp. 44–56.

³⁹The word "technology" is being used here in its anthropological sense: as something "much larger" than a tool itself; specifically, a system of rules and procedures prescribing how tools are made and used. K.D. Shick and N. Toth, *Making Silent Stones Speak* (New York: Simon & Schuster, 1993), p. 49. Likewise, the word "tools" is being used here in a very broad sense that includes traditional tools like desks, chairs, PCs, telecommunication networks, and so forth, but that also includes such decidedly non-traditional "tools" as stairways, decks, dining room tables, and even fireplaces.

⁴⁰R. Fulghum, "A Bag of Possibilities and Other Matters of the Mind," *Newsweek*, fall/winter 1990, p. 90. Fulghum observes that: "There is no such thing as 'the' human brain—no generic brain. What we know, how we know it, our strategies for learning and our idiosyncratic ways of being alive, differ significantly from person to person. The implications of this [for business] are almost overwhelming." *Ibid.* I have borrowed the term "mind's best work" from: D.N. Perkins, *The Mind's Best Work* (Cambridge: Harvard University Press, 1981).

⁴¹D. Ackerman, *A Natural History of the Senses* (New York: Random House, 1990), p. 294. Ben Franklin also used to write while soaking in a bathtub—an innovation (the bathtub, that is) that he brought to the United States from France in the 1780s. *Ibid.*, p. 296.

⁴²W. Manchester, *A World Lit Only by Fire: The Medieval Mind and the Renaissance* (Boston: Little, Brown and Company, 1992), p. 139. Here is how Luther himself described the experience:

These words "just" and "justice of God" were a thunderbolt to my conscience. . . . I soon had the thought [that] God's justice ought to be the salvation of every believer. . . . Therefore it is God's justice which justifies and saves us. And these words became a sweeter message for me. This knowledge the Holy Spirit gave to me on the privy in the tower. *Ibid.*

⁴³Ackerman, *Senses*, p. 293.

⁴⁴P. Ackroyd, *Dickens* (New York: HarperCollins Publishers, 1990), p. 222. Throughout his life, Dickens also positioned his bed on an exact north-south orientation, using arguments about "earth currents and positive and negative electricity" to explain his admittedly strange behavior.

⁴⁵Ackerman, *Senses*, pp. 293–94.

⁴⁶J. Alter, "Real Life with Gary Trudeau," *Newsweek*, 15 October 1990, p. 61.

⁴⁷"Just Dig While You Work," *Time*, 28 March 1988, p. 57. According to Cray: "I work when I'm at home. . . . I work for three hours and then I get stumped, and I'm not making progress. So I quit, and I go out and work in the tunnel." Ibid.

⁴⁸L. Harper, "Vanderbyl Design," *HOW*, December 1992, p. 86. Vanderbyl notes, however, that this only seems to work when he flies first class: "Normally when I fly coach and start drawing, there's an old lady sitting next to me telling me all about her grandson who's an artist. But in first class, it's quiet. I put my earphones on, order some red wine and just start cranking through." Ibid.

⁴⁹See, for example, L. Tiger, *The Pursuit of Pleasure* (Boston: Little, Brown and Company, 1992). This may well help to explain why some people really *do* prefer to work on decks or porches on a beautiful summer morning—or sitting in front of a roaring fire on a cold winter afternoon.

⁵⁰See, for example, R. Kotulak, "Outside World Helps to Shape Brain," *Columbus (Ohio) Dispatch*, 16 May 1993, p. 6B; and Ackerman, *Senses*, esp. 200–202.

⁵¹M. Schrage, *Shared Minds* (New York: Random House, 1990), p. 15. As Schrage puts it:

When we're with other people, our surroundings can't help but influence us. We behave differently depending on where we are. Discussions over dinner are qualitatively different from discussions over desks. . . . While personality matters, environment often determines which part of the personality is revealed. Privacy, intimacy, or accessibility are as often imposed by where we are and what technologies surround us as they are by the way we feel at any given moment.

⁵²D.B. Sutherland Jr., "Technology and the Contemporary Design Firm: Reflections on Time, Space, Tools, and the Mind's Best Work," *Design Management Journal*, Spring 1993, p. 40.

⁵³Senge, *Discipline*, p. 10.

⁵⁴One company that has taken some interesting steps in the direction suggested by Senge, and along the lines suggested by Schrage and my experience at FITCH, is Steelcase, Inc. in its innovative Corporate Development Center that sits in the middle of the prairie just outside Grand Rapids, Michigan. For a discussion of the Steelcase facility see:

"Science and Design," *Interior Design*, August 1990, p. 198; and

"Steelcase HQ Sparks Innovative Design and Functional Solutions," *Building Design and Construction*, June 1989, p. 82. For a discussion of technology infrastructure planning at FITCH see:

T. Peters, *Liberation Management* (New York: Alfred A. Knopf, 1992), pp. 414–415;

Sutherland, "Reflections;" and

"New Tools, New Opportunities: Inventing the New Design Firm," *The Jeffe Report*, May 1992, pp. 9–11.

⁵⁵In 17th and 18th century England, the coffee house *was* the "white-collar workplace" for most of middle class society. The great English insurance firm, Lloyd's of London, actually took its name

from Lloyd's Coffeehouse, opened by Edward Lloyd on London's Tower Street in 1687 or 1688 and subsequently removed to Lombard Street. Insurance underwriters had been renting regular booths, meeting clients, and transacting business at Lloyd's for more than 80 years before "the company" removed to an "office" building. The point of the coffeehouse was not just coffee, of course—they also served tea and chocolate, but *dialogue* (in the sense the term is used by Senge). According to contemporary accounts, people frequented coffeehouses not only to conduct business, but to discuss political and literary topics, as well, and to catch up on the latest news. It was estimated that at the turn of the 18th century there were some 3,000 coffeehouses in London or one coffeehouse for every 200 people in the city! See, for example:

W. Schivelbusch, *Tastes of Paradise: A Social History of Spices, Stimulants, and Intoxicants*, trans. David Jacobson (New York: Pantheon Books, 1992), pp. 49–70.

⁵⁶See, for example, S. Shirley, "A Company without Offices," *Harvard Business Review*, January–February 1986, pp. 127–135.

⁵⁷See, for example, J. Tilsner, "But Will They Get Their Own Water Coolers?," *Business Week*, 19 July 1993, p. 32.

⁵⁸The answer, of course, is that people *will* occasionally lose them, break them, etc., and they probably *will* even use them on occasion for some non-business purposes. This is inevitable. However, consider the lost opportunity cost by *not* providing the best possible tools to a firm's employees so that they may "work," quite literally, 24 hours a day, 7 days a week, 365 days a year.

⁵⁹For an interesting perspective on the historical importance of "home and hearth" see W.J. Garry, "Keep the Home Fires Burning," *Bon Appétit*, March 1993, p. 14. It is interesting to note that some Japanese companies have been experimenting with *aromacology*—the controlled introduction of smells into white-collar work environments—as a productivity booster. See:

T. Dunkel, "Its Time to Wake Up and Smell the Rosemary," *Insight*, 15 June 1992. See also: A. Kondoh, *Survey of New Office Design Trends* (Tokyo: Uchida Yoko Co. Ltd., 1990).

⁶⁰Peters, *Liberation*, pp. 416–20; and "New Tools."

⁶¹Shirley, "Company."

⁶²Peters, *Liberation*, pp. 397–399.

⁶³Tilsner, "Coolers?," p. 32. To quote Chiat-Day chairman Jay Chiat: "Offices are a 19th century concept." Ibid.

⁶⁴M. Weiser, "The Compute for the 21st Century," *Scientific American*, September 1991, pp. 102–104.

⁶⁵"Home Sweet Home," *Good Morning America*, ABC, WRIC, Richmond, Va., 11 August 1993.

⁶⁶Peters, *Liberation*, p. 399.

⁶⁷Senge, *Discipline*, pp. 341–345.

⁶⁸See Watzlawick, *Reality*, esp. 41–61.

⁶⁹A. Farnham, "How to Nurture Creative Sparks," *Fortune*, 10 January 1993, pp. 94–97. See also: P.F. Drucker, "The New Society of Organizations," *Harvard Business Review*, September–October 1992, pp. 95–104.

Session 2: Personal Travel

<i>The Future of Transportation in Society: Forces of Change</i>	113 - 4
Dr. Barbara C. Richardson	
<i>The Smart Highway Project: Smart Highways, Smart Vehicles, Smart Engineering</i>	141 - 5
Ray D. Pethtel	
<i>Hypercars: The Next Industrial Revolution</i>	155 - 6
Dr. Amory B. Lovins	
<i>Flying Cars</i>	183 - 7
Prof. Steven C. Crow	

54-85
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The Future of Transportation in Society: Forces of Change

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Transportation Beyond 2000:
Engineering Design for the Future
September 26 - 28, 1995

Overview

- Transportation as an integral part of society
- Customer satisfaction
- Societal issues
- Historical trends
- Forecasts
- Forces of change and transportation implications
- Needs of customers
- Questions for new transportation systems

Roles of Transportation in Society

- To provide access for people to life's activities
- To move goods

Vehicle Miles of Travel in the U.S. 1991 (millions)

Highways	2,174,786
----------	-----------

Auto	1,542,846
------	-----------

Truck	623,625
-------	---------

Bus	8,315
-----	-------

Local Transit	3,348
---------------	-------

Rail	25,941
------	--------

Amtrak	313
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Freight	25,628
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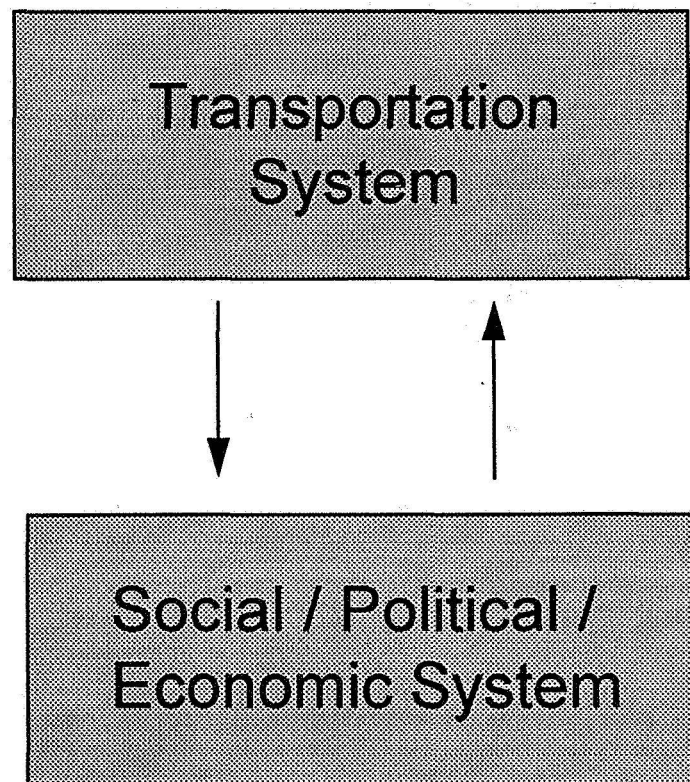
Air	8,364
-----	-------

Water	1
-------	---

Domestic Transp.	2,212,440
------------------	-----------

Source: USDOT: National Transportation Statistics (1993)

Interaction of the Transportation System and the Social / Political / Economic System



Societal Factors Relating to Transportation Systems

- Access
- Demographics / family structure
- Distribution effects
- Economic
- Isolation
- Land use
- Organizational
- Safety and security
- Traffic effects
- Transportation issues
- User acceptability
- Users / non-users of systems

Factors Affecting Transportation Use

Regulation
Litigation
Legislation



Technology Transportation Market
Push → Use ← Pull

Market Pull

Defined by needs, desires, and characteristics of actors in the market place.

CUSTOMER SATISFACTION

Customers for Transportation

- Women
- Men
- Youth
- Aged
- Sick
- Wealthy
- Poor
- Healthy
- Handicapped
- Single
- Married
- Urbanites
- Ruralites
- Suburbanites

Population Growth WWII to Present

U.S. Total	56.1%
------------	-------

Metropolitan Areas ($\geq 50,000$ population)	76.1%
---	-------

Central Cities	49.9%
----------------	-------

Suburban Areas	200.0%
----------------	--------

Source: Rosenbloom, Sandra. A Vision of Emerging Transportation Service Requirements Twenty Years in the Future. Final Draft. Tucson: Drachman Institute for Travel and Regional Development Studies. February 1995, p.37.

Immigrants to U.S. by Region of Birth (Thousands)

	1971-1980	1981-1990
Europe	801.3	705.6
Asia	1,633.8	2,817.4
North America	1,645.0	3,125.0
South America	284.4	455.9
Africa	91.5	192.3

Source: U.S. Bureau of Census. Statistical Abstract of the United States 1994 (114th Edition) Washington, D.C. Table 8.

Residence as % of Population - 1988

Central Cities	33%
Suburbia	46%

Poverty Rate - All Families - 1991

Central City Families	17.2%
Suburban Families	7.2%

Distribution of Poor - 1980

Central Ghettos	24 Million
	(8.9% of all poor in U.S.)
Black	67%
Hispanic	33%

% of Population in Central Cities in Extreme Poverty

1970	5.2%
1990	10.7%

Source: Rosenbloom. February 1995, pp. 38-40.

Changes in Marital Status and Living Arrangements

	<u>1970</u>	<u>1991</u>
% of adults who are married	72	61
% of children living with 2 parents	85	72

Source: Saluter, Arlene F. Marital Status and Living Arrangements:
March 1991. Current Population Reports, Population Characteristics.
Series P-20, No.461. U.S. Bureau of the Census.

Living Arrangements of the Elderly, 1991 Age 65 and Over (Non-institutional Residents)

<u>Living</u>	<u>%</u>
Alone	31.2
With spouse	54.1
With other relatives	12.5
With non-relatives only	<u>2.2</u>
 Total: 30,093,000	 100.0

Source: Saluter, Arlene F. Marital Status and Living Arrangements: March 1991. Washington, D.C.: U.S. Bureau of the Census. Current Population Reports. Series P-20, No. 461.

% of Married Women Employed

1960	30
1990	60

% of the Work Force Who Are Women

1950	35
1990	42

% of Women 35 - 44 Working Outside the Home

1960	40
1992	77

% of Married Women With Children Under 6 Working Outside the Home

1960	18
1970	30
1994	60

Source: Rosenbloom. February 1995.

**“Forecasting is difficult,
especially when it
involves predicting the
future.”**

Yogi Berra

U.S. Population 2015

(Thousands)

	<u>1995</u>	<u>2015</u>
Men 25 - 64	66,624	75,277
Men over 64	13,699	20,453
Women 25 - 64	68,690	81,651
Women over 64	19,951	26,274

Source: U.S. Bureau of the Census. Statistical Abstract of the United States. 1994 (114th Edition). Washington, D.C. Table 11.

U.S. Population Projections by Age, Race, and Hispanic Origin (Thousands)

	1990	2015	% Increase
White	209,150	247,544	+18
Black	30,620	42,817	+40
American Indian, Eskimo, Aleut	2,075	2,905	+40
Asian and Pacific Islander	7,570	19,922	+163
Hispanic	22,554	45,871	+103

Source: Day, Jennifer Cheeseman. Age, Population Projections of the U.S. by Sex, Race, and Hispanic Origin: 1993 - 2050. Current Population Reports, P.25-1104. U.S. Bureau of the Census.

Forces of Change and Their Transportation Implications

Lower Residential Density

- Longer trips to more dispersed destinations
- More personal car use
- More likely to be alone in car
- More trips
- More elderly in suburbs

Household Changes

- Increased travel demand with increased number of households
- Increased travel demand with decreased number of adults per household

Forces of Change and Their Transportation Implications (continued)

Movement of Jobs to Suburbs

- Increased suburb-to-suburb commute
- Increased central city-to-suburb commute
- Diminished reliance on transit
- Increased use of personal vehicles

Increase in Working Mothers

- Increased need for linked trips
- Decreased ability to use inflexible and time-consuming modes

Forces of Change and Their Transportation Implications (continued)

Increase in Elderly Population

- Increased need for transportation usable by elderly
- Needs not met by public transportation
- Increased use of personal vehicles
- Need for vehicles to meet ergonomic requirements

Forces of Change and Their Transportation Implications (continued)

Increase in Immigrant Population

- Different ergonomic, experiential, and language backgrounds need to be addressed in transportation system

Increase in Poverty in Inner Cities

- Transportation from inner city to suburban job locations

Some Needs of Customers

Working Mothers	Ease of linked trips
Aged	Independence, easy-to-use transportation
Youth	Access to school, after school activities
Immigrants	Easy to understand instructions
Urban	Quick travel in congested areas; reverse commuting
Rural	Access to centers of activity

Some Needs of Customers (continued)

Suburban	Access to centers of activity
Poor	Access to jobs, education, health care ...
Handicapped	Access to jobs, education, health care ...
All People	Social interaction, access

Will New Transportation Systems ...

- Enable inner city residents to access suburban jobs?
- Be affordable to all potential users?
- Equitably address social priorities?
- Be usable by handicapped people?
- Enable elderly people to live independently longer?
- Be understandable, usable, and affordable by immigrants?

Will New Transportation Systems ... (continued)

- Be usable by youngsters without adult supervision?
- Meet the ergonomic needs of the potential users?
- Contribute to human interaction and diminish society's sense of isolation?
- Afford access to the elderly who have "aged in place" in the suburbs?
- Have "seamless interfaces" between available modes?

Will New Transportation Systems ... (continued)

- Be safe and user friendly?
- Users be secure?
- Users' privacy be violated?
- Be acceptable in the marketplace?
- Harm society in any way?
- Contribute to the social good?

THE SMART HIGHWAY PROJECT:

**SMART HIGHWAYS
SMART VEHICLES
SMART ENGINEERING**

TRANSPORTATION BEYOND 2000: Technologies Needed for Engineering Design



Langley Advanced Transportation Workshop

September 26-28, 1995

RAY D. PETHTEL

**Interim Director, Center for Transportation Research, and
University Transportation Fellow**

CENTER FOR TRANSPORTATION RESEARCH

- ◆ Interdisciplinary
- ◆ Multidisciplinary
- ◆ Decentralized

Resources:

- ◆ 14 Core Staff Positions
- ◆ 24 Students (50% MS, 50% Ph.D.)
- ◆ 14 Cooperating Faculty
- ◆ 6 Cooperating Labs
- ◆ \$9 Million Total Value of Research Awarded

DESIGNATIONS AND RELATIONSHIPS

- ◆ ITS Research Center of Excellence (FHWA)
- ◆ Mid-Atlantic University Transportation Center
- ◆ Associate Participant, National Automated Highway System Consortium (NAHSC)
- ◆ Capital Beltway Safety Advisory Committee
- ◆ Participant, Virginia Transportation Research Council (VDOT)

**SURFACE TRANSPORTATION FACILITIES SERVE
A VARIETY OF PURPOSES AND ARE EXTREMELY
IMPORTANT TO MODERN LIFESTYLE**

- ◆ Provide for the efficient movement of people and goods necessary to support a modern economy and mobile lifestyle
- ◆ Serve adjacent land uses
- ◆ Enhance personal mobility
- ◆ Give access to services and support economic growth
- ◆ Permit flexibility in the selection and maintenance of quality of life choices

THE “SMART HIGHWAY” WILL BE A TEST BED AND TEST TRACK FOR INTELLIGENT TRANSPORTATION SYSTEMS (ITS) RESEARCH

- ◆ The road is a critical part of the highway network in the region and is expected to carry 20,000 vehicles each day by the year 2015.
- ◆ This is the only ITS research facility being designed and built from the ground up to accommodate evolving technologies in each subsequent stage of construction. Will serve as a full scale test bed and test track for AHS research in cooperation with the NAHSC.
- ◆ The potential research market associated with the Smart Highway could be up to \$100 million over the next 20 years.
- ◆ Environmental studies are completed, and preliminary design is underway. Final Public Hearing is October 18, 1995 in Blacksburg.

THE NATIONAL AUTOMATED HIGHWAY SYSTEM CONSORTIUM (NAHSC) WILL DEFINE FUTURE HIGHWAY SYSTEMS

- ◆ The NAHSC is a federally established entity which is intended to define the nature of future highway systems and then develop and demonstrate one or more prototypes of a fully automated highway.
- ◆ The NAHSC budget is \$150 million for research over the next 7 years.
- ◆ This is a public/private partnership involving top national industries including General Motors, Delco Electronics, Lockheed Martin, Hughes Aircraft, Bechtel, Parsons Brinckerhoff. Also includes Carnegie-Mellon, Caltrans, UC Berkeley PATH, and USDOT.
- ◆ Virginia Tech was selected in the first group of Associate Participants and will serve in a variety of research areas including evaluation.

NATURE OF SUBSTANTIVE RESEARCH

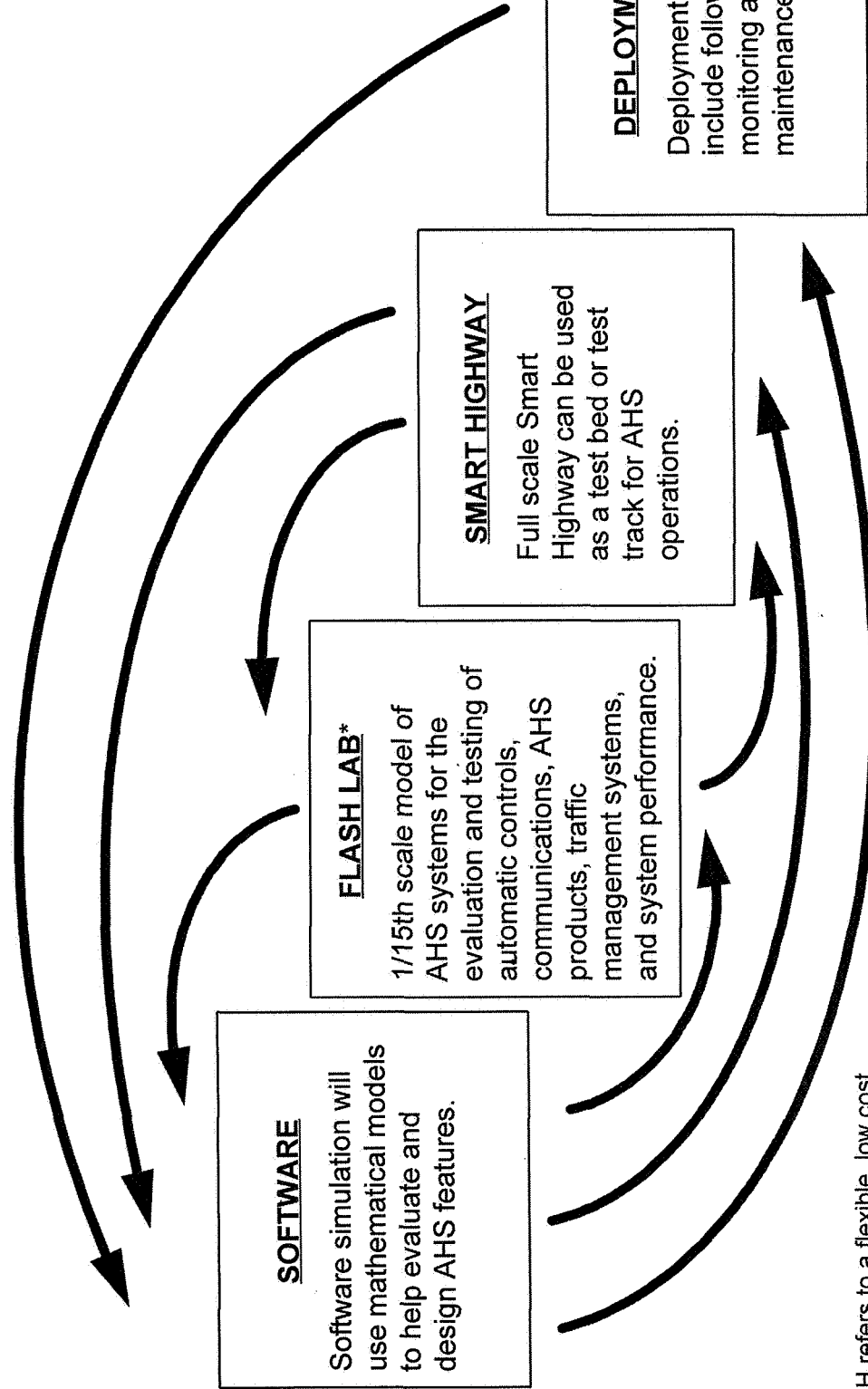
Short Term:

- ◆ Automated vehicle identification, as on Dulles Toll Road
- ◆ High speed weigh in motion, as at I-81 Troutville weigh station
- ◆ Road surface sensing for freezing and pavement condition

Longer Term:

- ◆ Vehicle to roadside communications
- ◆ Vehicle control such as lane following, lateral control, automated steering, and headway distance
- ◆ Collision avoidance
- ◆ Automatic trip routing
- ◆ Fully automated highway systems

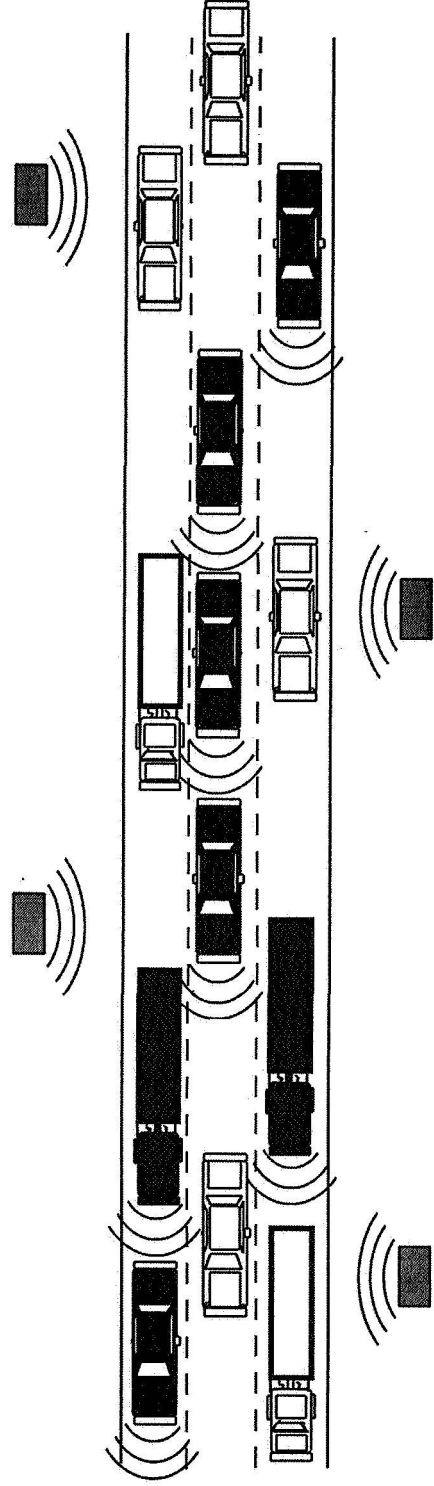
VIRGINIA TECH'S EVALUATION APPROACH



*FLASH refers to a flexible, low cost, automated, scaled highway system. The system can be portable.

COOPERATIVE INFRASTRUCTURE MANAGED SYSTEM

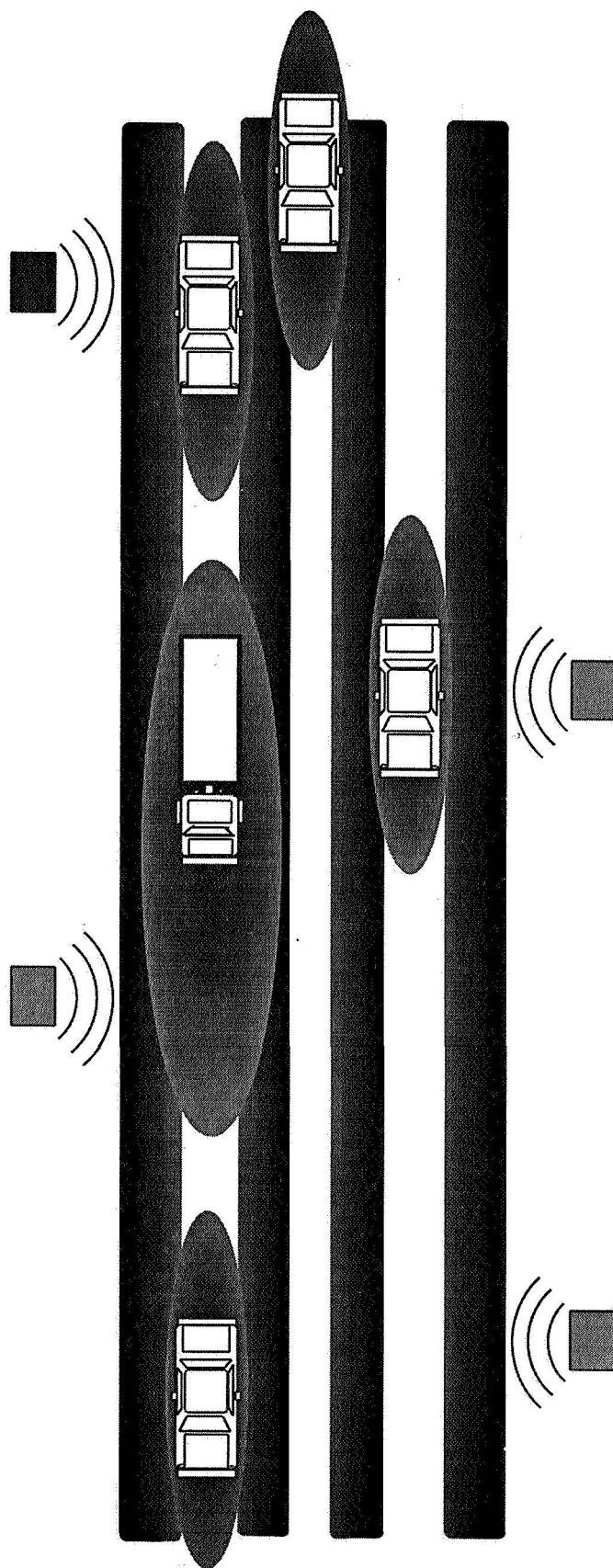
- ◆ Ultra-wideband communication in roadway beacons
- ◆ Obstacle detection and other sensors in vehicles
- ◆ Vehicle/infrastructure cooperation
- ◆ Global management



COOPERATIVE INFRASTRUCTURE MANAGED SYSTEM CHARACTERISTICS

- ◆ Infrastructure impact is low to medium
- ◆ Instrumentation distribution is mixed between highway and vehicles
- ◆ Uses global strategy to synchronize traffic
- ◆ Permits active infrastructure control
- ◆ Gives access to conventional and automated vehicles
- ◆ Operating speed is variable by conditions, up to 100's possible
- ◆ Includes all vehicle classes
- ◆ Uses rubber tire vehicles
- ◆ Power is on-board vehicles

CONTROLLER FIELD ILLUSTRATION



ULTRA-WIDEBAND TECHNOLOGY FEATURES

- ◆ Low cost device due to solid state electronics
- ◆ Highly accurate radar ranging (better than centimeter accuracies possible)
- ◆ Good range (200 feet currently, 2 miles or better expected)
- ◆ Multiple communications possible
- ◆ Interference not a problem
- ◆ Can penetrate solids and go around corners

OTHER ITS APPLICATIONS OF ULTRA-WIDEBAND

- ◆ Automatic vehicle identification
- ◆ Advanced traveler information systems (roadside to vehicle information)
- ◆ Transportation planning
- ◆ Advanced traffic management systems (probe vehicle tracking, link travel time)
- ◆ Parking management (space sensor)
- ◆ Collision avoidance (proximity detector, blind spot detector, headway sensor)
- ◆ Automated highway system (cooperative ranging, vehicle to vehicle communications, vehicle to roadside communications)

THE PRODUCT OF THIS TECHNOLOGY BEYOND 2000

- ◆ Foot off the gas
- ◆ Hands off the wheel
- ◆ Brain off the driving task

To produce a safe, modern, efficient transportation system



Hypercars: The Next Industrial Revolution

by Amory B. Lovins, John W. Barnett, and L. Hunter Lovins
The Hypercar Center, Rocky Mountain Institute

11 August 1993, revised 26 February 1995

1739 Snowmass Creek Road, Snowmass, Colorado 81654-9199, USA
phone 303/927-3851, FAX 303/927-4178, Internet 'hypercar@rmi.org'
[area code changes 2 April 1995 from 303 to 970]

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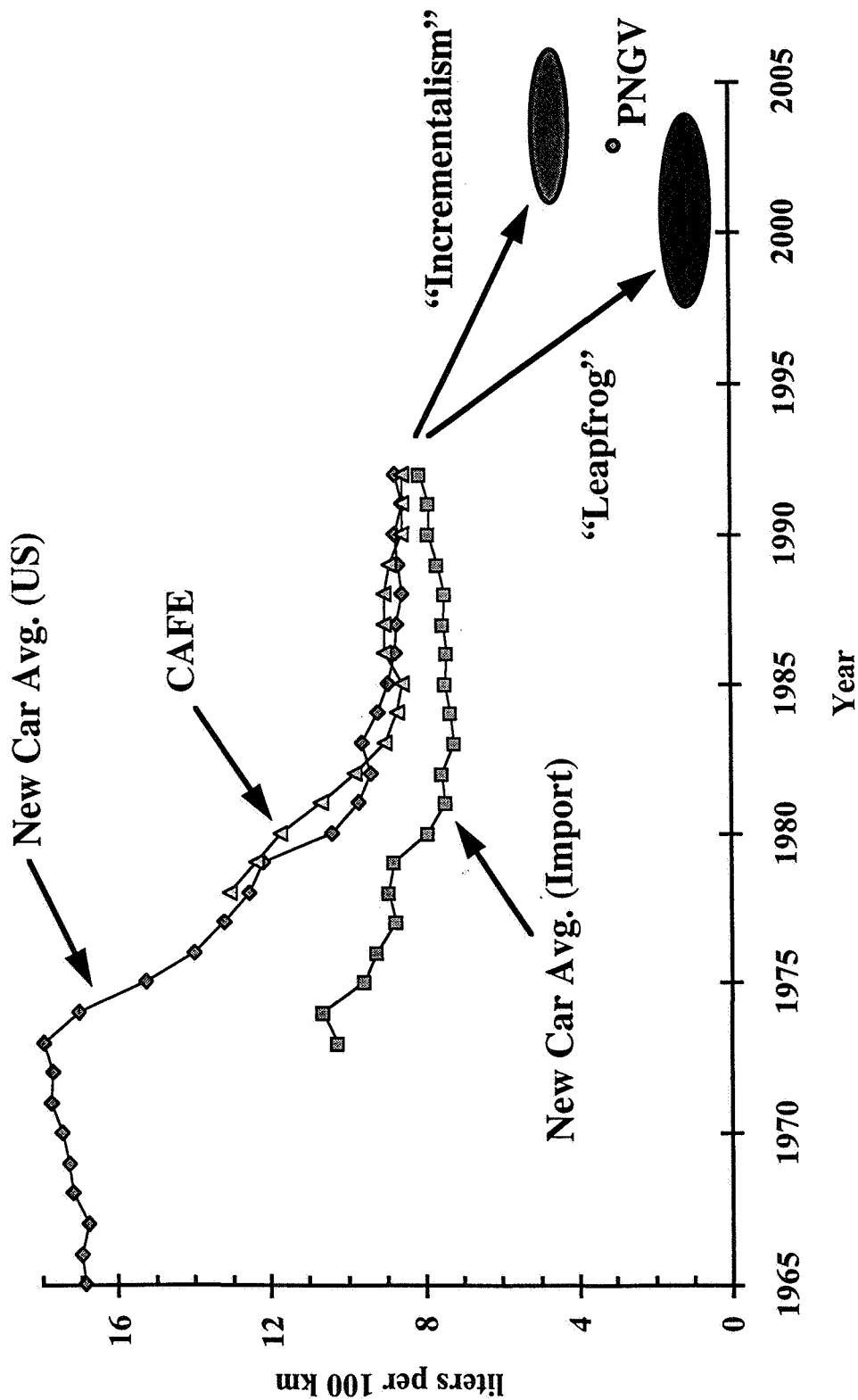


What are hypercars?

- not incremental but ‘leapfrog’
- an artful fusion of the best existing technologies
 - ultralight / slippery (improves efficiency $\sim 2-2\frac{1}{2}\times$)
 - hybrid-electric (improves efficiency $\sim 1.3-1.5\times$)
 - high-level system integration, meticulous attention to detail
- superior characteristics: for a family car,
 - $\leq 0,6-1,6$ litre/100 km ($\sim 150-\geq 400$ mi/USgal) composite ratings
 - ≥ 100 times cleaner; probably cleaner than battery-electrics
 - great fuel flexibility, convenient for liquids and gases
 - safer, sportier, more comfortable/quiet/durable/beautiful
 - probably cheaper
- completely different in technology, manufacturing, and sales
- profound implications—perhaps the biggest change in industrial structure since the microchip
- important cultural and market barriers need attention
- can buy time, but can’t solve the transport problem

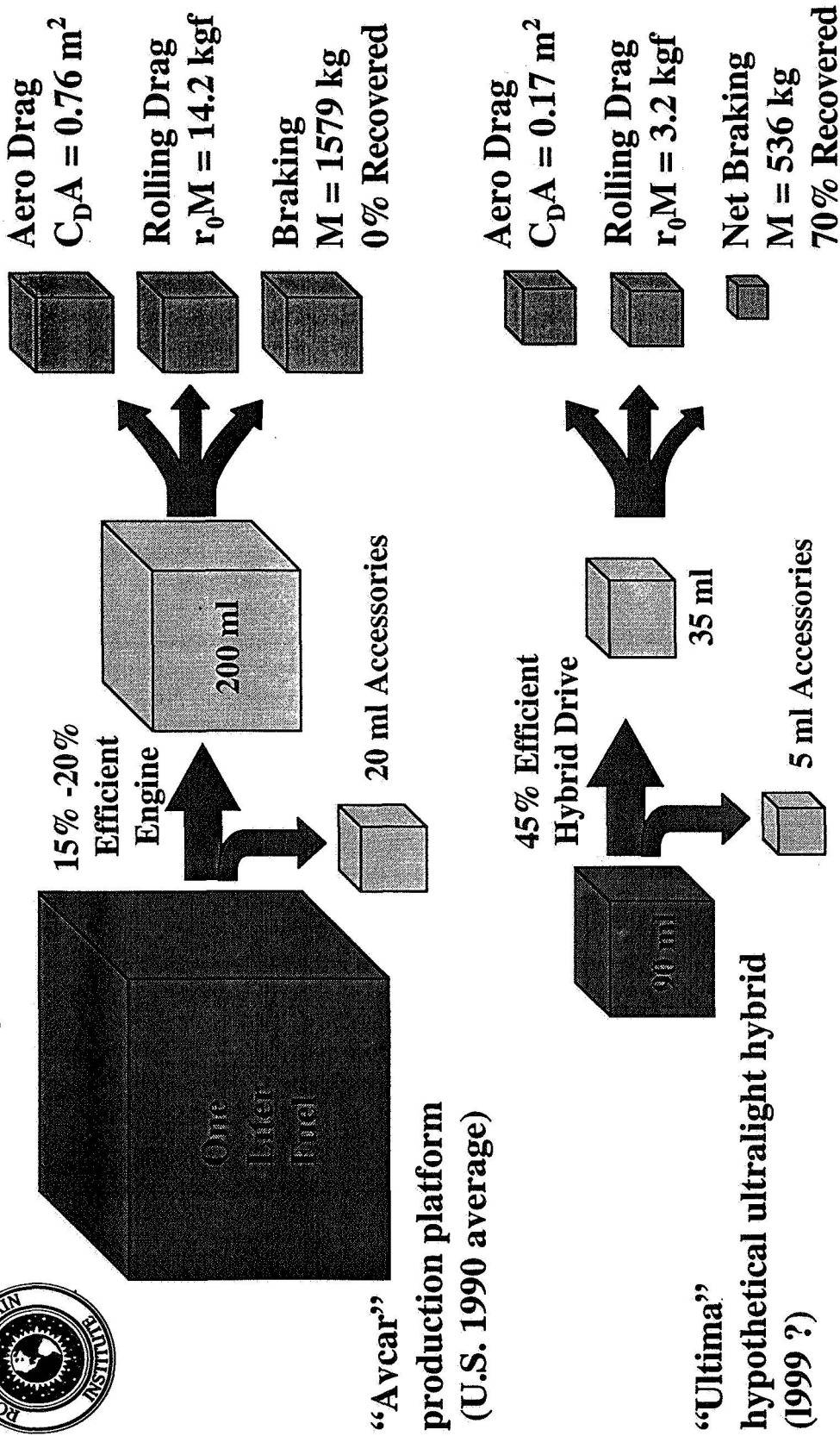


Trend Is Not Destiny ?





Two ways to drive 12 km in the city



In highway driving, efficiency *falls* because there is far more irrecoverable loss to air drag (which rises as v^3) and less recoverable loss to braking.



Reducing drag coefficient, C_D

1970: norm $\sim 0,5-0,6$
1992: U.S. average $0,33$, best sedan $0,29$, best productionized 2-seat $0,18$
1992: best worldwide production platform (Adam Opel) $0,255$
1921: Rumpler 7-seat Tropfenwagen (midengine prototype) $0,28$
1985: Ford Probe V concept car $0,137$ ($< F-15$'s C_D !)
1987: Renault Vesta II 4-seat concept car $0,186$
1991: GM Ultralite 4-seat concept car $0,192$
1990s: likely practical limit w/ passive boundary-layer control $\sim 0,08-0,10$

Reducing frontal area, A (m^2)

1992: average U.S. 4/5-seat production platform $\sim 2,3$; 2-seat Honda DX $1,8$
1987: Renault Vesta II 4-seat concept car $1,64$
1991: GM 4-seat Ultralite concept car $1,71$

So today's typical $0,33 \times 2,3 m^2 C_D A = 0,76 m^2$; GM's Ultralite, $0,33 m^2$; the best parameters separately shown for 4-seaters, $0,137 \times 1,64 = 0,22 m^2$ (30% of today's); and edge-of-envelope, $\sim 0,08 \times 1,5 m^2 = 0,12 m^2$ (16% of today's). We assume $C_D A = 0,27$ near-term, $0,17$ later, $\sim 0,13$ edge-of-envelope.



Reducing the mass, M , of 4-seat cars

Mass compounds by $\sim 1.5\times$ in heavy cars, $\sim 5\times$ in ultralights.

Typical 1990 U.S. production platforms had curb mass $\sim 1\,443$ kg. However, mainly light-metal concept cars built in $\sim 1983\text{--}87$ included:

. VW	5-seat	Auto 2000	779 kg
. Volvo	4-seat	LCP 2000	707 kg
. Toyota	5-seat	AXV Diesel	649 kg
. Renault	4-seat	Vesta II	475 kg
. Peugeot	4-seat	ECO 2000	449 kg

The unoptimized 1991 4-seat GM Ultralite weighed 635 kg; the 1994 4-seat ESORO H301 hybrid, ~ 670 kg including 230 kg batteries; the 1989/90 2-seat Kägi OMEKRON electric, 490 kg including 260 kg batteries. Detailed I.95 mass budgets for a 5-seat series hybrid yield $\sim 400\text{--}500$ kg. Thus <500 kg curb mass is practical now, 400 in ~ 1998 . (USEPA test mass is 136 kg more.)

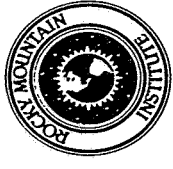
Reducing tyre rolling resistance, r_0

Modern radials' $r_0 \approx 0.007\text{--}0.010$; best mass-produced, ~ 0.0062 ; best made by 1990 with good handling (by Goodyear), 0.0048; 1993 state-of-the-art, even less. We assume $0.006\text{--}0.007$ including parasitic mechanical losses.



Hybrid-electric drives

- . The wheels are driven wholly or mostly electrically by up to 4 ?hub-integrated switched reluctance motors (a British technology that is inherently smaller, lighter, cheaper, stronger, faster, quieter, and more efficient, rugged, fault-tolerant, and controllable than asynchronous or permanent-magnet motors). Braking is electronic and regenerative.
- . Electricity is made onboard as needed in a tiny IC or EC engine, gas turbine, thermophotovoltaics, or fuel cell, *e.g.* an Otto (probably Orbital-derivative 2-stroke) $\eta = 0,3$ engine or $\eta = 0,5$ semiadiabatic Diesel.
- . A few batteries (or a C-fibre superflywheel or ultracapacitor) store braking energy for hill-climbing and acceleration—*not* for range, since lead-acid batteries have $\sim 1\%$ as much energy per kg as fuel. Only ~ 0.5 kWh is needed; 2.5 kWh & 40 kW of hybrid-optimized NiMH weigh ~ 50 kg.
- . Later, ideally a modular fuel cell (?monolithic solid-oxide, self-reforming and reversible, thereby eliminating the buffer storage too).
- . Dramatically lower accessory loads and parasitic mechanical drag.
- . Extremely light but crashworthy (advanced polymer composites); max. payload/mass; designed like an airplane, not a tank; ‘fly-by-light/power-by-wire’, smart active suspension, and powerful integrative software.



Advantages of hybrid-electric drive

- Using fuel for range cuts driveline mass $\sim 4\times$ below battery cars'.
- Mass savings compound faster than with other drivelines.
- Engine ~ 10 kW: sized *not* for peak acceleration but for $\sim 1\text{--}3$ kW cruising load + engine's $\sim 4\text{--}8$ kW share of gradeability + <1 kW accessories.
- Engine runs at a point (series) or over a small range (parallel), not over a big map, *doubling* typical Otto-engine efficiency. (A typical U.S. car's engine, to accelerate $0\text{--}97$ km/h in 11 s, is oversized $\sim 6\times$ highway, $24\times$ city.)
- Engine never idles—it shuts off when enough energy has been stored.
- Regenerative braking recovers $\sim 70\%+$ of braking energy (demonstrated w/permanent-magnet motors, higher with switched reluctance, highest with nonbattery buffer too; requires excellent software and electronics).
- Efficiency and emissions *improve* with traffic congestion, because regenerative braking makes them better in city than in highway driving.

Strongly synergistic w/ultralight: lower irrecoverable losses (air and road drag) leave more energy recoverable from braking; mass decompounding is bigger with both ultralights *and* hybrids, and biggest with both together.



Key parameters and USEPA composite fuel efficiencies of selected 4-seat existing and hypothetical cars (modelled per Rohde & Schilke)

C_{DA}, m^2	M, kg	r_0	E_{acc}	C_{DAM}	engine η	driveln η	regen η	l/100 km	mi/gal
production cars: typical U.S. 1990									
0,76	1 443	0,009	$\approx 1,0$	1 095	$\sim 0,30$	$\sim 0,60$	0	8,00	29,4
demonstrated concept car: GM Ultralite 1991 (1,5-1 83-kW 2-stroke engine)									
0,33	635	0,007	$< 1,0$	208	unpubl	unpubl	0	3,79	62

hypothetical synthetic-polymer-dominated ultralight hybrids:

'Conservativa' worst-case illustration (uncontroversial parameters)									
0,40	700	0,008	0,80	280	0,35	0,75	0,60	2,44	97
'Gaia' near-term design ('optimized Ultralite', standard petrol engine)									
0,27	580	0,007	0,50	154	0,30	0,90	0,70	1,61	146
'Ultima' advanced design ('state-of-the-shelf'—very light, good Diesel)									
0,17	400	0,006	0,30	68	0,50	0,90	0,70	0,63	376
'Imagina' (aero++, fuel cell or best Diesel, C-flywheel/ultracapacitor)									
0,13	*400	0,005	*0,25	52	*0,56	0,96	*0,88	*0,38	*614

*Still not edge-of-envelope, because these parameters can be further improved with demonstrated 1994 technologies. Engine efficiency is peak (BSFC_{min})— ~ 280 g/kW_{mech} h is $\eta_{max} = 0,30$; driveline efficiency is engine-output-shaft-to-wheels; regenerative braking efficiency is wheel-to-wheel, including storage in/out η and square of driveline η .



Sensitivity tests confirm wide flexibility

1. *Hybridizing the 635-kg Ultralite yields ~1,2–2,1 l/100 km.*
 - With $\eta = 0,30$ engine, 0,9 driveline, 0,7 regeneration, 2,07 l/100 km = 114 mi/gal; with $\eta = 0,50$ engine, 1,24 l/100 km = 190 mi/gal.
2. *Performance remains impressive even with 300-kg payloads.*

• Conservativa + 300 kg	2,70 l/100 km	87 mi/gal
• Gaia + 300 kg	1,82 l/100 km	129 mi/gal
• Ultima + 300 kg	0,74 l/100 km	318 mi/gal
• Imagina + 300 kg	0,45 l/100 km	523 mi/gal
3. *Ultima-class performance can come by many reasonable routes.*
 - With $\eta = 0,50$ powerplant (good small Diesel) and $M = 635$ kg = GM Ultralite, Ultima yields 0,79 l/100 km = 298 mi/gal.
 - At Ultima's original 536-kg test mass, $\eta = 0,30$ powerplant (ordinary petrol engine) yields 1,04 l/100 km = 225 mi/gal.
 - Thus neither 400-kg curb mass nor $\eta = 0,50$ powerplant is essential.
 - Thus the ~0,6–1,6 l/100 km performance domain leaves both technological flexibility and an appropriately wide safety margin.



Conclusion: $\sim 10\times$ efficiency gains now feasible

- . A 4-passenger ultralight hybrid can be an order of magnitude more efficient than today's production platforms if it combines the best demonstrated levels of powerplant and regeneration efficiency, mass, and rolling resistance, plus
 - . *either* proper credit for the efficiency of a modern switched reluctance driveline (a well-demonstrated technology)
 - . *or* C_{DA} one-fifth below the best demonstrated big-car levels.
- . Gaia uses conservative accessory loads and engine, driveline, and regeneration efficiencies.
- . The high levels of efficiency claimed, therefore, appear quite robust under aggressive but realistic assumptions.
- . However, the *best* combinations of parameters for each segment require extensive analysis, experiment, and test-marketing.



1991 concept car illustrates ultralight strategy

General Motors conceived in IV.91, road-tested in XII.91, and showed in I.92 a 4-seat concept car, called the Ultralite, that:

- took 50 people, \$4–6M (~8 h of GM's N. Amer. losses), & 100 d to make
- 635-kg curb mass including 4 airbags, 56% below typical
- 6-piece, 191-kg (unoptimized) carbon-fibre/epoxy composite body
- roomy inside (Chevrolet Corsica), tiny outside (Mazda Miata)
- top speed 218 km/h, accelerates 0–100 km/h in 8 s (like Mustang)
- $C_D = 0,192$, $A = 1,71 \text{ m}^2$, so C_{DA} only 43% of the U.S. norm
- twice as efficient as the average new U.S. car: 5,22 l/100 km city, 2,90 highway, 3,85 composite (62 mi/USgal)
- cruises at 81 km/h and 2,35 l/100 km on 3,2 wheel kW (Audi 100–71%)
- Lisbon to Moscow or New York to Los Angeles on ~110 l of petrol
- *not* hybridized: rather, a conventional 1,5-l, 2-stroke, 3-cylinder IC engine (in-line direct-injection stratified-charge, 83 kW, 79 kg) in removable rear 'pod' with conventional Saturn automatic 4-speed transaxle
- should be very crashworthy and meet ULEV emission standard
- not yet optimized (mass, engine,...) nor engineered for production



Ultralights can be affordable

- Carbon fibre in X.94 cost ~\$18/kg, 20× more than steel; 12× is expected XII.95. But what matters is cost per *car*, not per kg:
- Carbon fibre is stiffer and stronger than steel but 3/4 lighter, so 2–3× fewer kg are needed. In many uses, other and cheaper fibres are as good or better (glass, aramid,... offer better elongation and toughness).
 - Of the cost of a typical steel car part, only ~15% buys steel; the other 85% pays for its shaping and finishing. But 'net-shape' composites emerge from the mould virtually ready-to-use, in complex, sleek forms.
 - Composites' mouldability into large, complex units can cut parts count by ~100×: the basic body can have not ~300–400 but only ~2–6 parts.
 - Those few light, easily handled parts can fit precisely together (tolerance down to a few μm) with ~90% less assembly labour and space.
 - Coated-epoxy moulding dies cost ~50–90% less per copy than steel dies: fewer parts, fewer dies per part, and cheaper materials and fabrication.
 - Composite colour-moulding could eliminate painting—the hardest and dirtiest automaking step, often half of steel body parts' total cost.
 - Collectively, these advantages offset (or more) higher fibre cost/kg.



Manufacturing and sales would be transformed

- Ultralights are not just another kind of car but a whole new culture—as different as fax is from telex or computers from typewriters.
- Tooling for a steel car takes a thousand engineers about two years. But epoxy tooling's short life and very quick fabrication supports fast cycles, short time-to-market, continuous improvement, small production runs, and strong product differentiation—a striking strategic advantage.
- Production time is probably less per car: moulding is slow and parallel, not fast and serial, but composites need far less assembly and rework.
- Personal-computer analogy: as cutting-edge design integration turns into standard recipes, clonemakers can undertake local assembly using commodity elements from Intel, Seagate, Microsoft,... Will hypercars' powerplants, motors, storage devices,... be so very different?
- As with PCs, production with the cheap tooling could be small and local.
- Just-in-time, zero-inventory manufacturing-to-order could greatly reduce today's ~50+% markup, so even if hypercars cost more to *produce* (unlikely), they could still be profitably *delivered* at a lower price.
- Their radical simplification and exceptional inherent reliability may also permit onsite maintenance, just as with mail-order PCs today.



Ultralight can be ultrasafe

Design and materials are far more important than mass. The structures and restraints that protect people weigh little. Also:

- short stops, fast acceleration, nimble handling, superb traction/braking
- ultrastrong energy-absorbing materials (oriented-C-fibre monocoque,...)
- special composite structures developed for aerospace (buckling members, breakaway elements, filament-wound cruciform members, impact-belt circumferential hollow beams, cones,...) absorb $\sim 3\times$ more energy/kg than metal: e.g., three <400-g C-fibre conical shells can smoothly absorb the entire crash energy of a 600-kg car hitting a barrier at 40 km/h.
- less sophisticated composite cars have crash-tested very convincingly
- Indy 500 composite-car drivers limp away from 370 km/h crashes
- strong, bouncy car body can be designed to be launched not mashed
- design and materials prevent intrusion into passenger compartment
- much easier/faster/safer post-accident extrication than from steel
- mass decoupled from size, so wide track, long wheelbase and ridedown
- better visibility, quieter (hence less driver fatigue)
- mechanically more reliable, graceful failure, preventive diagnostics



Ultralight hybrids can be $\sim 100\times$ cleaner

Four effects multiply to make hypercars $\sim 10^{2-3}\times$ less polluting:

- . $\sim 10\text{--}25\times$ less engine displacement ($\sim 10\text{-kW}$ engine sized to tiny average load) slashes all emissions (though not linearly for NO_x)
- . for a given platform, operating the engine in a smaller map—with idle-off, regenerative braking, and no ‘command enrichment’—cuts small engines’ emissions per litre by a lot ($\sim 6\times$?)
- . further reductions, plausibly $\geq 2\times$, if engine is emission-optimized, especially for near-single-point operation (series hybrid)
- . cleaner fuels are convenient (CH_4 , H_2 ,...), saving another $\sim 2\text{--}\infty\times$

These nearly independent effects multiply: $10\text{--}25 \times 6 \times 2 \times 2 = \sim 240\text{--}600\times$ (much better w/special fuels or with fuel cells): good ultralight hybrids are cleaner *in* Los Angeles than battery-electrics! Therefore ‘zero’- (elsewhere-) emission rules should and probably will be revised to allow cleaner hybrids (‘virtual ZEVs’).



Cultural barriers in the car industry

- changing a diemaking, steel-stamping culture into a moulded-net-shape-materials/electronics/software culture is extremely challenging
- hypercar is more like a computer with wheels than like a car with chips
- systems integrators with rapid learning, no fear of new materials and products, and agile production may do better than automakers
- automakers are imprisoned by sunk costs treated as unamortized assets, as if it were better to write off obsolete capabilities later when they don't have a company than now when they do
- need net-shape presumption with fallback to metal, not the reverse
- determine best ways to manufacture with net-shape materials, then design car to exploit them, not the reverse
- redesign every part from scratch with zero-based mass budget: composites are *not* 'black steel'; if the part looks the same, it won't work
- *must kill your product with better new ones before someone else does*
- incrementalism is a bet-your-company choice (hope none of your competitors is faster); but leapfrogging on a risk-managed trajectory, first to ultralights and then to ultralight hybrids, lets you feel sorry for your former competitors—if and only if you do it first



Institutional barriers in the marketplace

- . world-market oil will probably keep getting cheaper for decades even without hypercars, much more so with them (1 nega-OPEC)
- . high petrol taxes cut driving moderately but car l/100 km little
- . fortunately, astronomical fuel taxes are not the only option:
 - . standards made U.S. new cars as efficient as Europe's and Japan's (or more so) despite fuel prices $\sim 2-5\times$ lower, and can be further improved
 - . but standards can be gamed and are static (no incentive to do better)
 - . 'feebates' look more dynamic: when you buy a new car,
 - . you pay a fee or get a rebate (which, how big depends on efficiency)
 - . each year, the fees pay for the rebates (revenue-neutral)
 - . the rebate for buying an efficient car can depend on the *difference* in efficiency between the new car you buy and the old car you scrap
 - . 'accelerated scrappage' rapidly improves fleet efficiency & emissions
- . start thinking now, urgently, about huge structural & job shifts
- . the car market is being transformed anyway; hypercars will accelerate this; a hardship or a lucrative opportunity?

Tank conversions vs. motorized butterflies

If you hybridize a heavy production platform in the hope of lightening it later...

- severe specific power requirements, big power switches
- big, heavy, short-lived, expensive buffer storage
- mass compounding drives total mass not down but up
- realistic control algorithm implies $>3\times$ engine map, low η
- complexity, mass, and cost often exceed Avcar's

But if instead you start with an IC-engine composite ultralight platform and *then* hybridize it...

- attractive, doubled-efficiency platform is saleable at once
- immediate switch from physical to virtual prototyping and from tool-steel dies to CAD/stereolith/epoxy molding dies
- order-of-magnitude lower product cycle times, assembly labor & space, and tooling costs—prompt, decisive lead
- peak power requirements become manageable (~ 60 kW)
- buffer storage *needs* only ~ 0.5 kWh; mass falls to ~ 50 kg (NiMH), then ~ 10 – 20 kg (C-fiber flywheel, ultracapacitor)
- battery buffers last, running at $\sim 20\%$ depth-of-discharge*
- series-hybrid engine map collapses to a point (or nearly so)
- insensitive to cost, W-h/kg, & W/kg of powerplants & fuels
- mass decompounding accelerates with radical simplification as more and more systems and components disappear
- packaging efficiency and aerodynamics improve further
- ~ 400 – 500 -kg curb mass becomes feasible for family sedans
- platform production cost starts to look very attractive

*w/2.5 kW-h @ hybrid-optimized 50 W-h/kg NiMH



We also need negakilometres and negacars

- . Hypercars can't solve the basic problem of too much driving by too many people in too many cars, and may well make it worse.
- . Even with 1-l/100-km, clean, recyclable, renewably fueled cars, a milliard Chinese or 8 million Los Angelenos driving them still wouldn't work: we wouldn't run out of oil or air, but we'd surely run out of roads and patience. Avoiding the constraint *du jour* requires not just better cars but also less automobility:
 - . end-use/least-cost strategy (the end-use is *access* not mobility)
 - . full and fair competition between all modes of access
 - . economic *glasnost*—prices that tell the truth
 - . transport *perestroika*—not centrally planned socialism for cars and free markets for all others, but a truly level playing-field
 - . innovative policy instruments: *e.g.*, congestion pricing, parking fees, commuting-efficient mortgages, advanced land-use planning, pay-at-the-pump car insurance, and making 'nega-km' markets (how much is it worth paying people to stay off the roads? probably a lot...) is this trip necessary? what kind of life and community do we want?



Conclusions about hypercars

- attack platform physics, not driveline; radical simplification
- ~5-20× efficiency gains are feasible by many available methods, though some near-commercial technologies are needed to reach the top end
- smaller but still major improvements in vans, heavy lorries,...
- further technical developments (best ways to configure, propel, manufacture, recycle, test, mend,...) are a need but not a barrier
- hypercars offer superior safety, emissions,..., probably affordability
- people will ultimately buy them because they're better, not to save fuel
- highly compatible with abundant/renewable liquid and gaseous fuels
- not clear who will do it best—unique market entry/exit opportunities
- leapfrog strategy is a competitive and public-policy imperative
 - do it first before it's done to you
 - potential for major economic disruption if bungled or ignored
- exhilaration and terror are both appropriate reactions; we can choose
- strong case for thoughtful policy intervention to smooth the transition
- requires strong parallel emphasis on comprehensive transport reform
- one of the greatest adventures in industrial history: ready or not, here it comes!

Advanced Ultralight Hybrids: Necessity and Practicality of a Leapfrog

Remarks to the Vice President's Automotive Technology Symposium #3
Structural Materials Challenges for the Next Generation Vehicle

U.S. Department of Commerce, Washington, D.C.

22-23 February 1995



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Whatever exists is possible: examples of fuel economy

parameter →	C_D	A	M_{curb}	r_0	E_{access} index	η_{engine}	$\eta_{driveline}$	η_{regen}	l/100 km	mi/gal
units →	—	m ²	kg	—	1990 Avcar ≡ 1.0	fuel to output	output shaft to wheels	wheel to wheel	EPA rating, 55/45 city/hwy., $M_{curb} + 136$ kg	
platform ↓										
Tested concept cars										
GM Ultra- lite 1991	0.19	1.71	635	0.007	?	?	?	0	3.79	62
ESORO H301 1994	0.23 ^a	1.8	670 ^b	0.007	?	?	?	?	~2.83 ^c , ~1.68 ^d	~83 ^c , ~140 ^d
Calculated variants (RMI approximation using Rohde & Schilke parametric model, SAE P-91)										
Ultralite with hybrid	0.19	1.71	681 ^e	0.007	0.50	0.30	0.90	0.60	1.97	119
H301 with series hybrid	0.23	1.8	457 ^{bf}	0.007	-0.50	0.30	0.90	0.60	1.87	126

a) Street measurement updated I.95; wind-tunnel is 0.19. b) After removing excess resin estimated by builder at ~30 kg, but including 230 kg of batteries in range-extender parallel design for 120-km combustion-free range (data updated I.95). c) If all electricity were made onboard @ $\eta = 0.30$, the Swiss urban/highway mix would be 2.83 l/100 km = 83 mpg. d) Calculated from (6 kWh grid electricity + 1 l gasoline)/100 km for typical Swiss city/highway mix, using conventional 8.78 (Bosch) kWh/l delivered- (not primary-)energy equivalence. Measured performance: hybrid-mode 2.94 l/100 km @ EU 90 km/h; electric-mode 10 kWh_{DC}/100 km urban, 7.44 in typical Swiss urban/highway mix. e) Relatively heavy design with no body optimization or mass decompounding; 50-kg NiMH buffer. f) If fuel were converted onboard to electricity @ $\eta = 0.30$. Mass = 670 kg^b incl. 16-kW engine – 230 kg batteries + 50 kg buffer batteries + 16 kg generator/controller – 49 kg mass decompounding @ 30%.

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Does the fat pupa shed weight 1 mg at a time— or crawl out, spread its wings, and fly away?

Builder	Seats	Materials	Body-in-white mass (kg) with closures...		Curb mass (kg)
			excluded	included	
Avcar, ~1994	4–5	Steel	~275	~372	~1,470
Advanced unibody est.	4–5	Steel	~195–220	—	~1,363–1,388 ^a
Ford AIV Taurus	4–5	Al, etc.	148	198	1,269 ^a
IBIS Assocs. est., 1994	4–5	E-glass, etc.	236	—	1,218
PNGV target, 1994	4–5	Carbon, etc.	138	186 (–50%)	882 (–40%)
GM Ultralite, 1991	4	Carbon, etc.	~140	191	635
RMI costing est., I.1995	4–5	Carbon, etc.	125–133	150	~530
ESORO H301, 1994 (I.95 upd)	4	75% glass, 5% C, 20% Aramid	72	120 ^b	~500 ^c
RMI bench-mark, I.1995	4–5	Carbon, etc.	—	100 or 140 ^d	482 near-, 410 midterm
WWU VRI Viking 23, 1994	2+ ^e	Carbon, a little Aramid	—	93	864 incl. 314 batts.
Kägi OMEK- RON, 1989–90	2	Carbon/ Aramid	34	—	490 incl. 260 batts.

a) Assuming no component optimization or mass decompounding. b) Excluding ~30 kg excess mass in bumpers and double-hinged doors, as estimated by builder, but including 2 bumpers and 4 composite seats. c) If redesigned from a 670-kg^b range-extender parallel hybrid with 230 kg of batteries to a series hybrid with 50 kg of batteries, assuming no electrical improvements or mass decompounding (though both would be available). d) Includes 29 kg special safety structures, 8 kg hardpoint mounting inserts, and 3 kg elastomeric bumper skins. e) A series hybrid not needing this design's batteries, 0.9-l IC engine, CNG tank, etc. could instead use the same structural mass budget to carry 4+ people.

SOURCE: *Hypercars: Materials and Policy Implications*, The Hypercar Center, RMI, 1995

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Are composite bodies affordable?

In 1995, RMI approximated body-in-white production costs by combining IBIS Associates' steel-unibody (and some composite-monocoque) input data with a relatively heavy RMI mass budget and with representative production costs provided by a leading composite-structures manufacturer

- for a thoroughly analyzed, proven production process
- to make a major (~30-kg) composite-monocoque part
- with moderate complexity and no Class A surfaces
- assuming tooling is discarded every 30k units
- with *no* capital economies of scaling up to 200 k units/y
- with semiautomation that could be substantially increased (RMI assumed 0–25% further reductions in labor cost).

RMI assumed composites with 70% (vol.) fiber, ranging

- from one-half to zero E-glass, the rest carbon
- from all-epoxy to all-urethane or equiv. resins (\$1–2/lb)
- at carbon creel prices from \$6.6/kg (Akzo-Nobel quotation for next tranche) to \$12/kg (expected end-1995, vs. ~\$15/kg X.94), though a hypercar industry's volume implies <\$2/kg
- for an open-aperture BIW mass of 125–133 kg,
- with *assembly* costs 10-20% those of a steel unibody (because the entire BIW is integrated into just a few parts).

These assumptions yielded BIW costs of \$1,100–2,080 (1994 \$), with midcase \$1,440—vs. \$1,500 for the high-volume IBIS steel-unibody BIW. Carbon's labor intensity was 2× higher, its capital intensity 5× lower. Carbon's cost advantage increases for *finished* auto bodies, since lay-in-the-mold color is cheaper than painting. Further research in spring 1995 will greatly refine this preliminary analysis.

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SOURCE: *Hypercars: Materials and Policy Implications*, The Hypercar Center, RMI, 1995

What makes hypercars safe

Principles

- Design and materials are more important than mass.
- Less mass makes the car less dangerous to others.
- Crash-protection structures and materials weigh little.

Implementation

Precrash avoidance

- nimbler handling, shorter stops, more stable dynamics
- wide stance, long wheelbase, reduced risk of hydroplaning
- all-time all-wheel antiskid braking and antislip traction
- better visibility, less noise, greater driver alertness

Crash energy management & trauma reduction

- Crush-cone array absorbing >100 kJ/kg
- Impact beam around passengers (>0.5 MN, 10–15 kg)
- Crush structures and ridedown distance (lots of room—car's size decoupled from mass, tiny driveline components)
- Pretensioning seatbelts, force limiters at anchor points, strong but resilient seats, ample head support
- Frontal and side-impact airbags for all, foam bolsters
- Collapsing steering column, breakaway pedals, etc.
- Shell fracture management (no intruding edges)

Postcrash recovery

- automatic 911 call on airbag deployment
- master electric shutoff, virtually leakproof fuel tank
- far easier access to / egress from passenger compartment
- much faster and safer extrication, by design

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Designing an elegantly frugal car that performs

<i>Frog gets smarter but doesn't leap</i>	<i>Leapfrog! New pond!</i>
Component-by-component Incremental changes to tradition Design from engine toward wheels, emphasizing driveline refinement Assume steel Accrete mass Largely ignore synergies Dis-integrate and specialize Huge design group, relay race Institutionalized timidity Baroque complexity Complex, therefore difficult	Whole platform Zero-based, ground-up, clean-slate Design starts with occupants and road loads, emphasizing platform physics Assume advanced composites* Eliminate and decompound mass Design to capture synergies Re-integrate; master details holistically Small design group, team play Skunkworks-style boldness Radical simplicity** Simple, therefore difficult

*“...[A]dvanced composite material development is outside our core technology, so we do not have manpower or facilities assigned to that development area.”

—Senior official, major U.S. automaker, October 1994

**“Everything should be made as simple as possible, but not simpler.” —Einstein

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Selected Publications

RMI's latest hypercar (formerly called supercar) publications include (please add 20% shipping in N. America):

- **"Reinventing the Wheels"*: January 1995 *Atlantic Monthly* feature nontechnically explaining the basic concepts and implications (#T94-29, 10 pp., \$5)—recommended as the best place for most readers to start
- **"Hypercars: Answers To Frequently Asked Questions,"* Jan. 1995 (#T95-1, 6 pp., \$3), supplements #T94-29
- **"Hypercars and Today's Cars: An Illustrated Comparison,"* Feb. 1995 (#T95-6, 2 pp., \$1.50)
- *"The Hypercar Packet,"* T95-1 & -6 plus energy diagram and several popular articles (#T95-16, 16 pp., \$5)
- *"Hypercars: The Next Industrial Revolution":* semitech. general storyboard, SI units (#T95-19, 20 pp., \$10)
- *"Policy Implications of Supercars":* semitechnical August 1993 storyboard (#T93-21, 8 pp., \$4)
- *"Zero Emission' Vehicles Aren't":* Letter in *The Electricity Journal*, June 1993 (#U93-17, 2 pp., \$1.50)
- *"Electrotechnologies":* Followup to U93-17, *Electricity Journal*, January 1994 (#U94-10, 1 p., \$1.50)
- *"Advanced Ultralight Hybrids: Necessity and Practicality of a Leapfrog,"* technical graphics from address to Vice President's PNGV symposium on structural materials, 22 February 1995, SI units (#T95-18, 10 pp., \$4)
- Front matter of *Hypercars: Materials and Policy Implications*, 31 Jan. 1995 (#T95-17, 15 pp., \$8)
- *Hypercars: Materials and Policy Implications*, proprietary technical analysis, August 1995, ~300 pp, \$10,000. to the industry (discounts available to qualifying nonprofit organizations); includes #T95-27, -34, -35
- *"Vehicle Design Strategies to Meet and Exceed PNGV Goals,"* technical parametric design analysis, SAE 951906, June 1995 (#T95-27, 43 pp., \$10)
- *"Address to 1993 Asilomar Conf. on Strategies for Sustainable Transportation"* (#T95-30, 11 pp., \$6)
- *"Hypercar: A Threat to the Oil Industry?,"* *Oil & Gas J.* reprint w/background, August 1995 (#T95-32, 6 pp., \$3)
- *"Amory Lovins: Moving Toward a New System,"* semitechnical interview from Scott Cronk's Society of Automotive Engineers (SAE) book *Building the E-motive Industry* (#T95-33, 7 p., \$4)
- *"Supercars: Advanced Ultralight Hybrid Vehicles,"* Wiley *Encyclopedia of Energy Technology and the Environment* reprint, basic annotated semitechnical primer, SI units, January/June 1995 (#T95-34, 32 pp., \$12)
- *"Costing the Ultralite in Volume Production: Are Composite Bodies-in-White Affordable?,"* SAE technical paper in press, August 1995 (#T95-35, 14 pp., \$10)

In addition, during 1995:

- The Hypercar Center will publish a semitechnical introduction to hypercar safety;
- *The Washington Post Magazine* is expected to print an article on reducing travel demand (#T95-7, ~3 pp., ~\$2);
- substantial broadcasting and other publications will continue, and a popular book is under consideration.

All new publications are announced in RMI's free *Newsletter*, and many are* or will soon be posted to the Institute's Internet homepages (above). If you are also interested in how RMI's work on hypercars evolved, you may want to read:

- *"Advanced Light-Vehicle Concepts":* RMI's first effort to assemble the general concept, as lecture notes for a National Academy of Sciences hearing—ideas mostly there but not yet fully synthesized (#T91-20, 15 pp., \$7)
- *"Supercars: The Coming Light-Vehicle Revolution":* the first thorough technical synthesis of the hypercar concept, from the June 1993 ECEEE symposium in Rungstedgård, Denmark (#T93-10, 34 pp., \$8)

Rocky Mountain Institute, founded in 1982, is an independent, nonprofit, nonpartisan resource policy center. Its ~40 staff foster the efficient and sustainable use of resources as a path to global security. RMI has earned a reputation for finding new solutions to old problems, or, better still, avoiding them altogether. The Institute works mainly on energy, water and agriculture, and transportation efficiency "green" real-estate development, local economic development, global security, and their interconnections. RMI is best known for having laid most of the conceptual and technical foundations of the \$5-billion-a-year "megawatt" (saved-electricity) industry and invented end-use/least-cost resource analysis.

Amory B. Lovins, 47, cofounded and directs research at RMI and at its Hypercar Center. A consultant experimental physicist educated at Harvard and Oxford, he has received an Oxford MA (by virtue of being a don), six honorary doctorates, a MacArthur Fellowship, and the Nissan, Mitchell, "Alternative Nobel," and Onassis Prizes. He has held a variety of visiting academic chairs; briefed nine heads of state; published 22 books and several hundred papers; lectured and broadcast extensively; served on the Department of Energy's senior advisory board; and consulted for scores of utilities, industries, and governments worldwide, mainly on advanced electric efficiency and more recently on new automotive concepts. *The Wall Street Journal's* Centennial Issue named him among 28 people in the world most likely to change the course of business in the 1990s.

PS/2E c:\winword\work\hpcpubs.doc ABL W/ff6 16.VIII.95

Flying Cars

Steven Crow
Aerospace and Mechanical Engineering Department
The University of Arizona

Presented at the NASA Langley Research Center
Transportation Beyond 2000 Workshop
26 September 1995

54-05
39472

Personal Aviation System Specifications

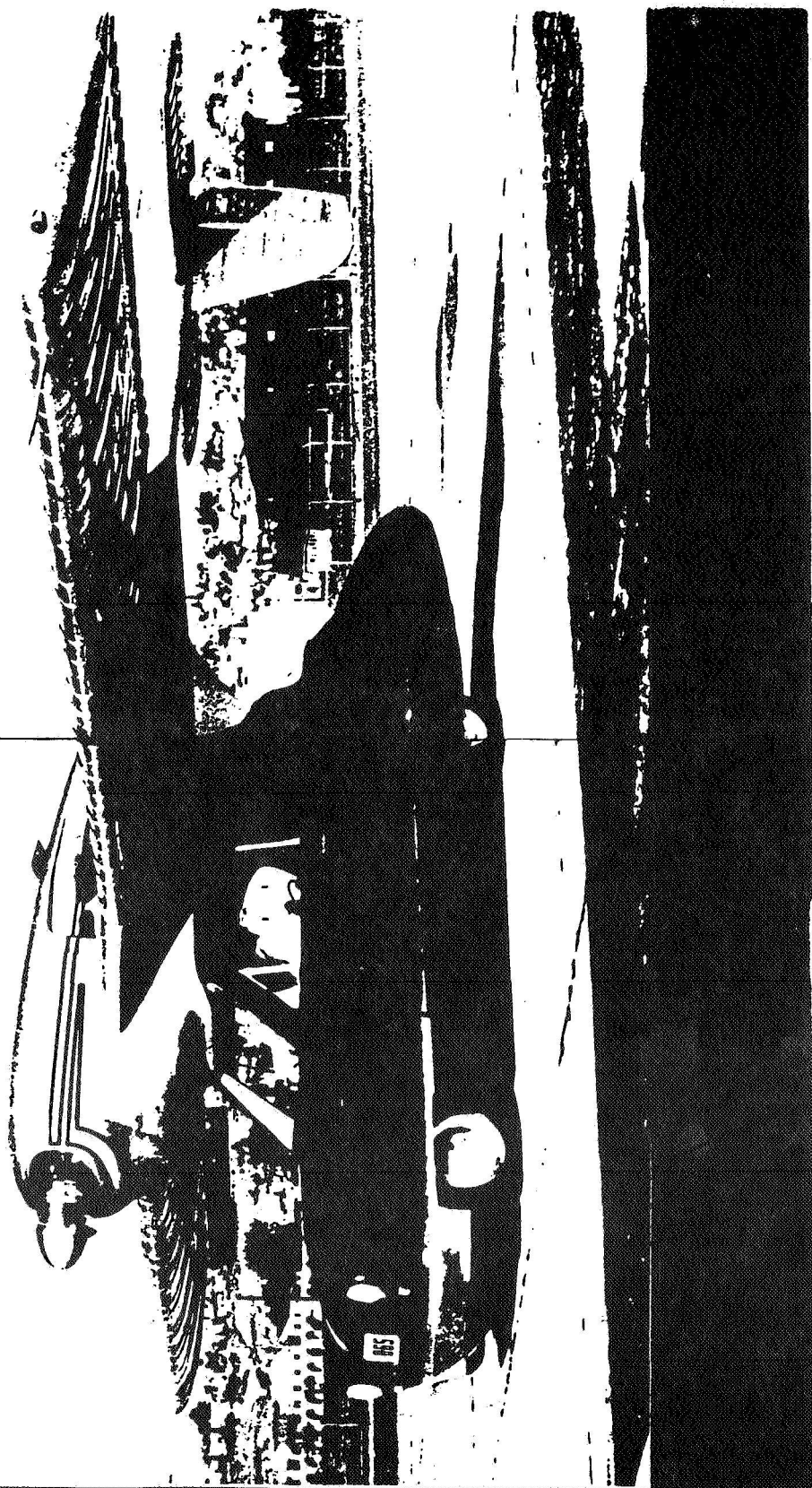
Price	Control
\$40,000	Robotic with display
Liability	Safety
Structured ownership	Equivalent to autos
Performance	Environment
Comparable to airplanes	Equivalent to autos
Convenience	Implementation
Portal to portal	Continuously profitable

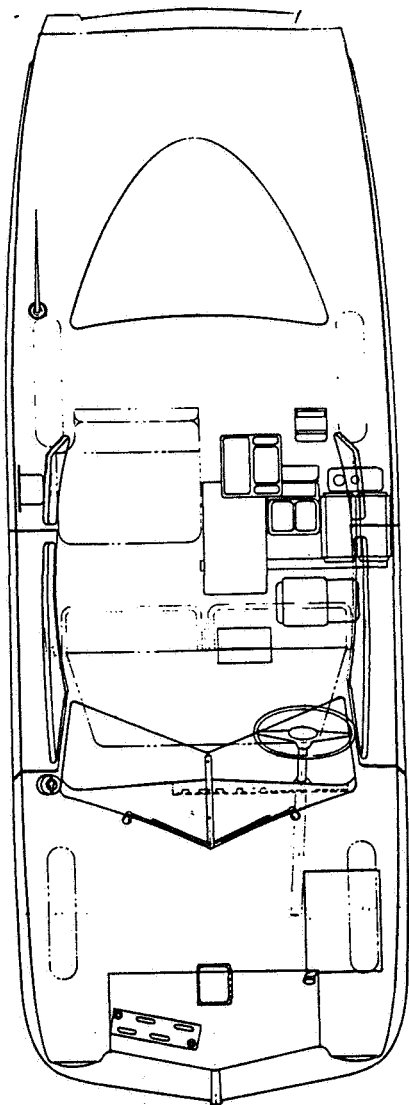
A new approach to the idea of the flying car was pioneered by Consolidated Valves, Inc., which featured a modular design, in which a basically standard car was sold to prospective buyers, and then they could add a large number of flight modules (wing surfaces and engine) for hire to the air

they and took less than five minutes to fit. The flying car was powered by a 26-hp Crosley car engine. The car was also built to fit into a standard parking space. The car was also built to fit into a standard parking space. The car was also built to fit into a standard parking space.

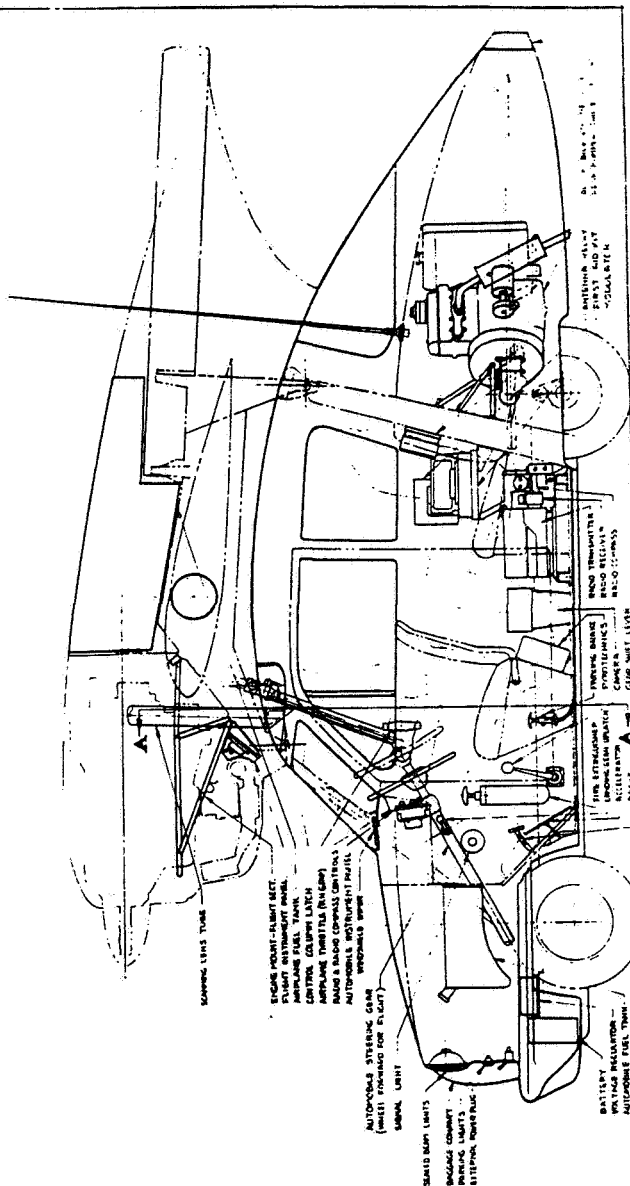
The car was also built to fit into a standard parking space. The car was also built to fit into a standard parking space. The car was also built to fit into a standard parking space.

and built to fit into a standard parking space. The car was also built to fit into a standard parking space. The car was also built to fit into a standard parking space.

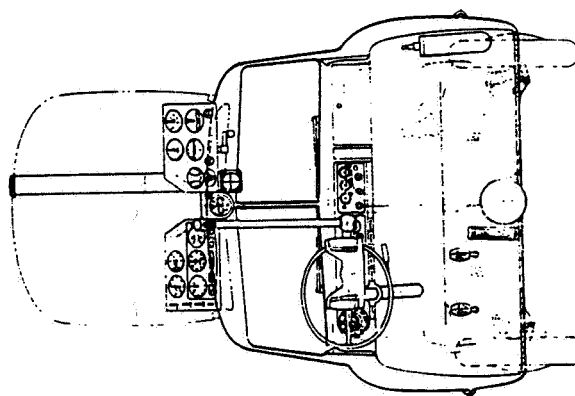




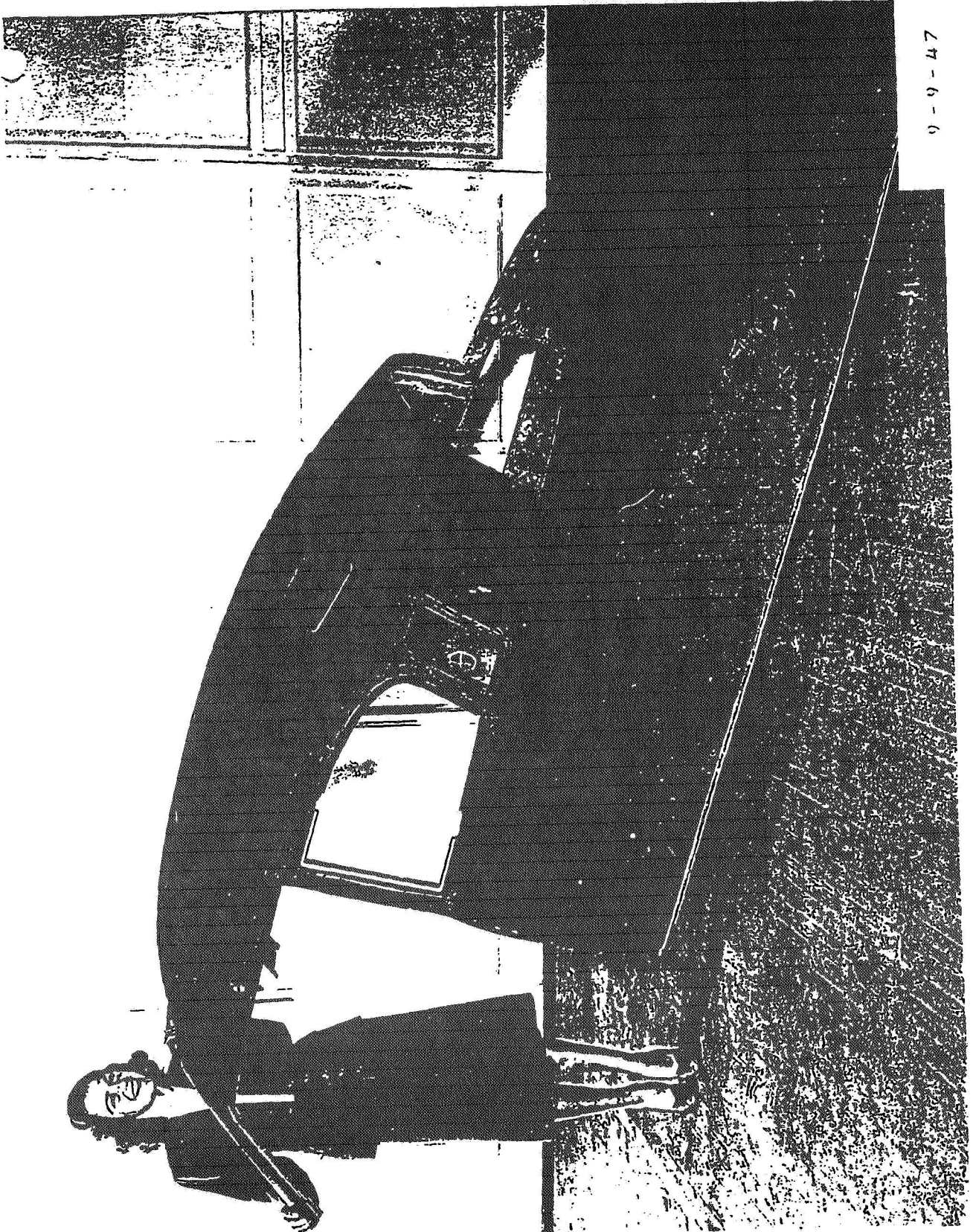
INBOARD PLAN



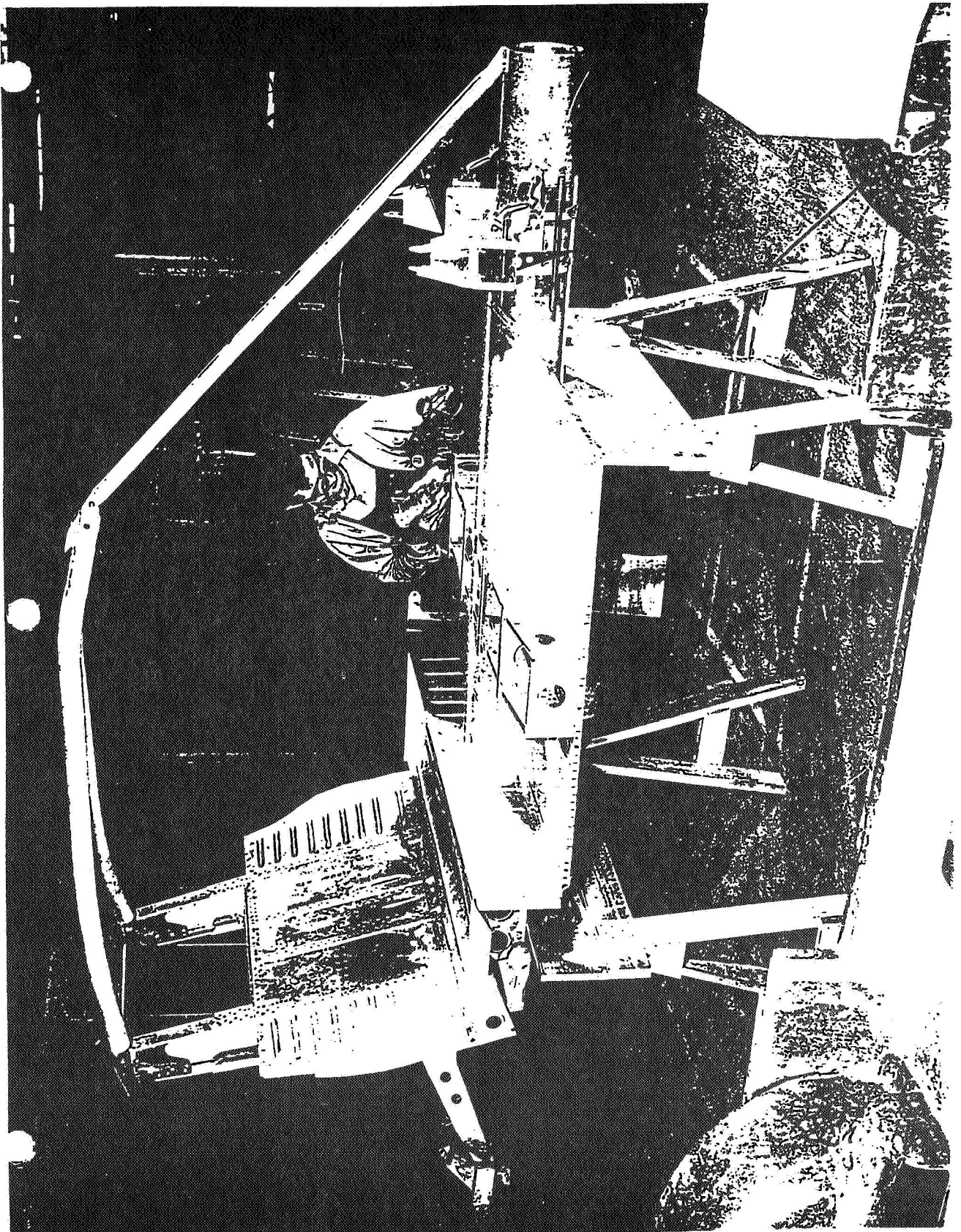
INBOARD PROFILE

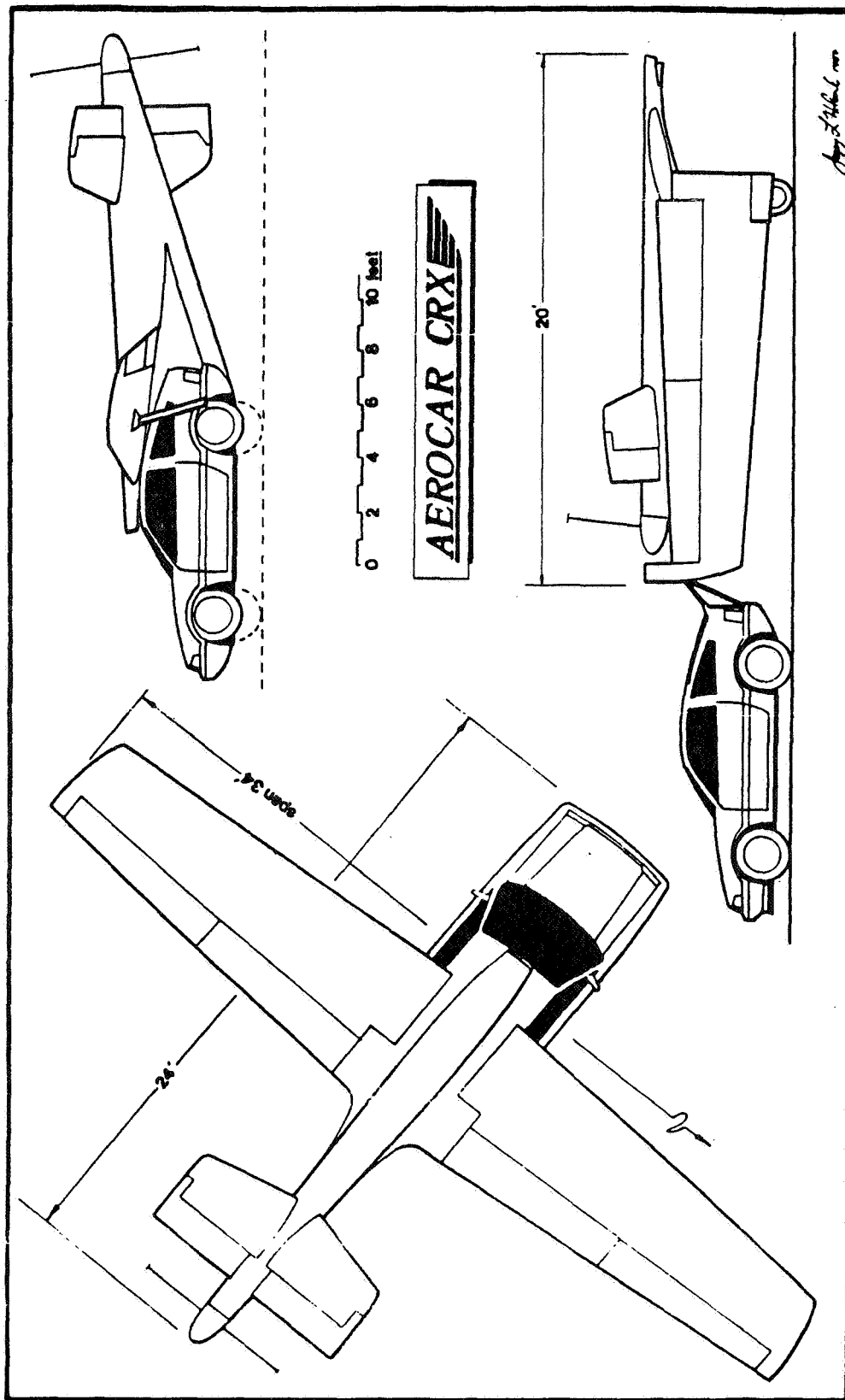


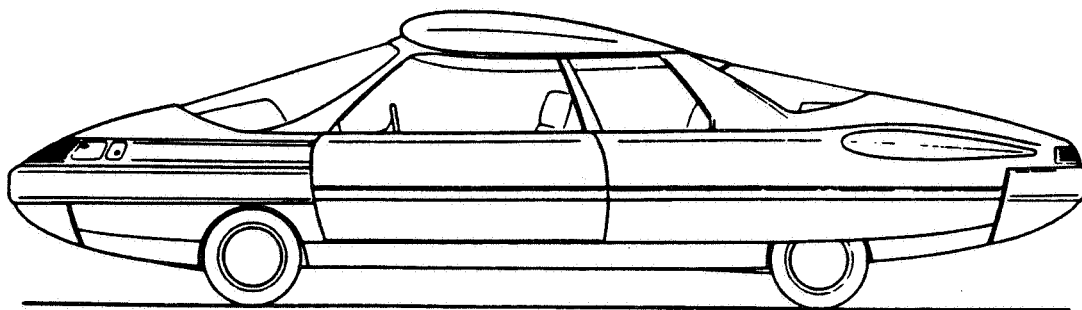
SECTION A-A



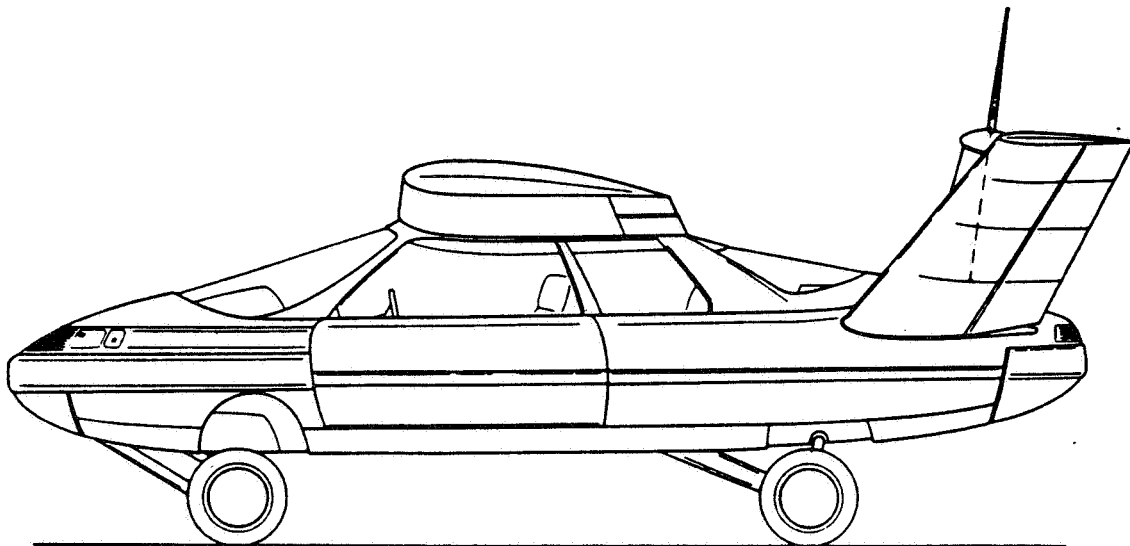
9-9-47



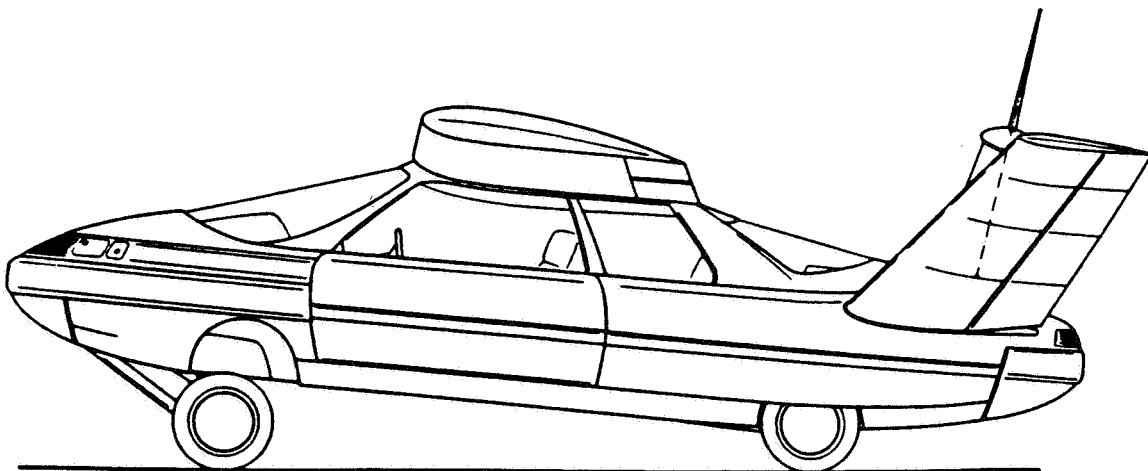




a) AUTOMOTIVE CONFIGURATION



b) AIRPLANE CONFIGURATION



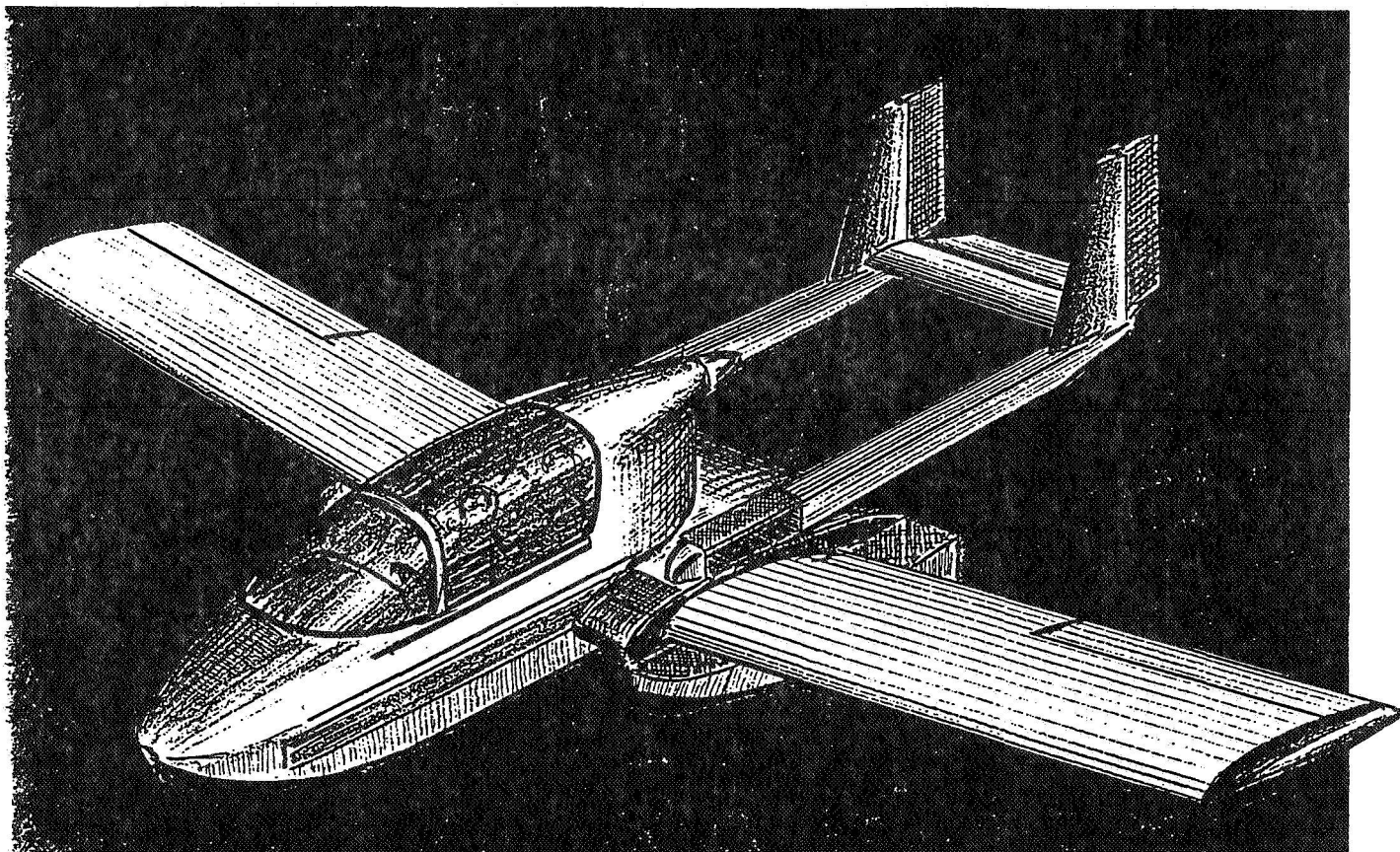
c) TAKE-OFF PHASE

FIGURE 7: ADVANCED FLYING AUTOMOBILE IN AUTOMOTIVE AND AIRPLANE CONFIGURATION

March/April 1994
Volume 3 Number 2
Issue 11
\$3.00

The Search for Utility

Roadable Aircraft



Schugt AIRCAR - 7 roadable amphibian concept

4 Roadable Amphibian and Other Aircars
More Schugt designs

17 Light Plane and Light Trailer
Towing an airplane on the highway

20 Flying Motorcycle
A complete flying and driving machine

22 The Mainair Skybike
More on the original flex-wing trike/motorcycle

24 New Joe Yasecko Design
Light single place roadable concept

2 From the Editor

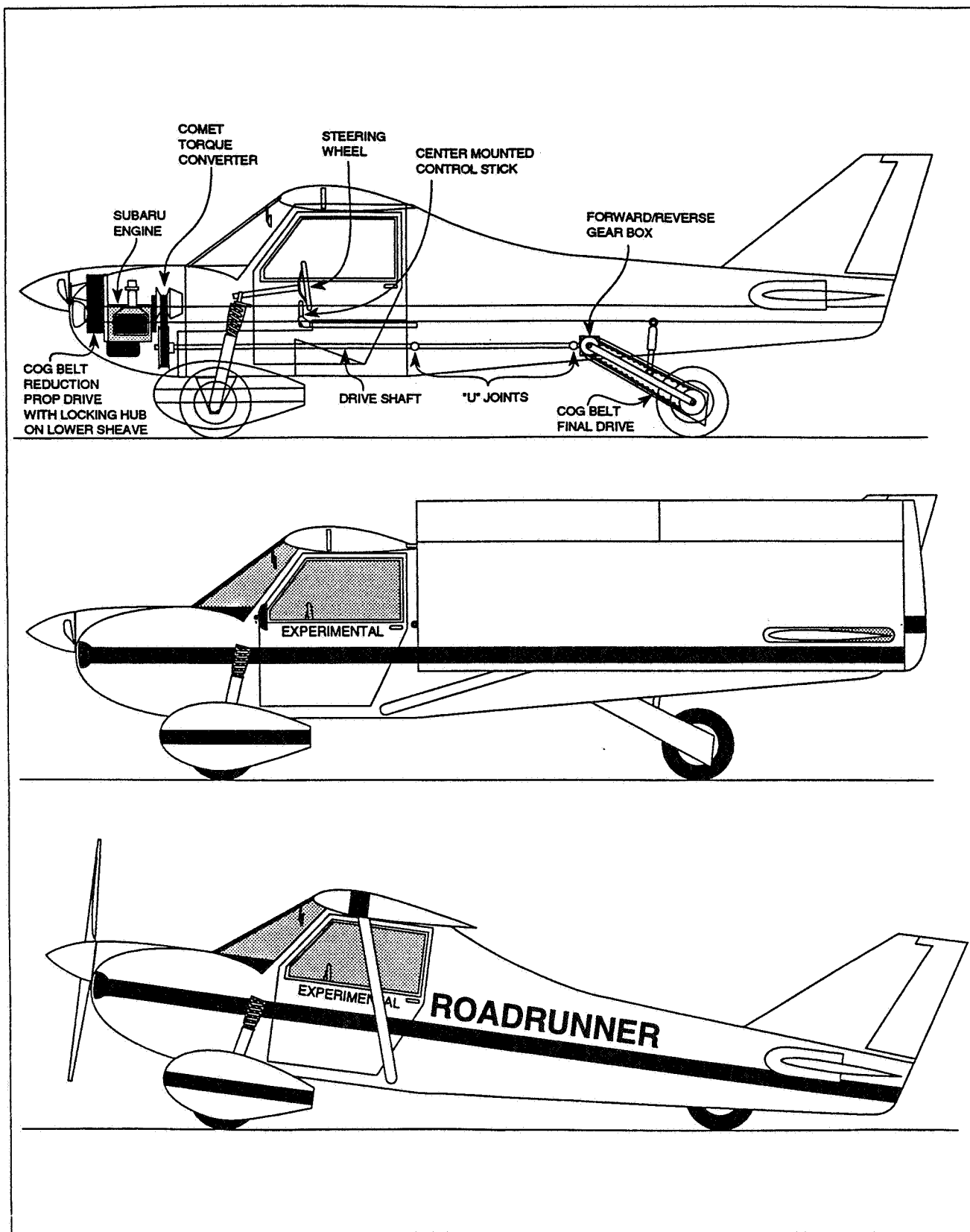
3 Oshkosh 94 Forum

3 Letters

19 Networking

27 Classified Ads

27 Back Issues



Inboard profile and side views for the High Wing ROADRUNNER.

Joe Yasecko

Joe does think the nose is too long and would need to be shortened. The tail booms are designed for construction of telescoping aluminum tubes.

The fuselage is based on a mold which he has already. Joe does think the nose is too long and would need to be shortened. The tail booms are designed for construction of telescoping aluminum tubes.

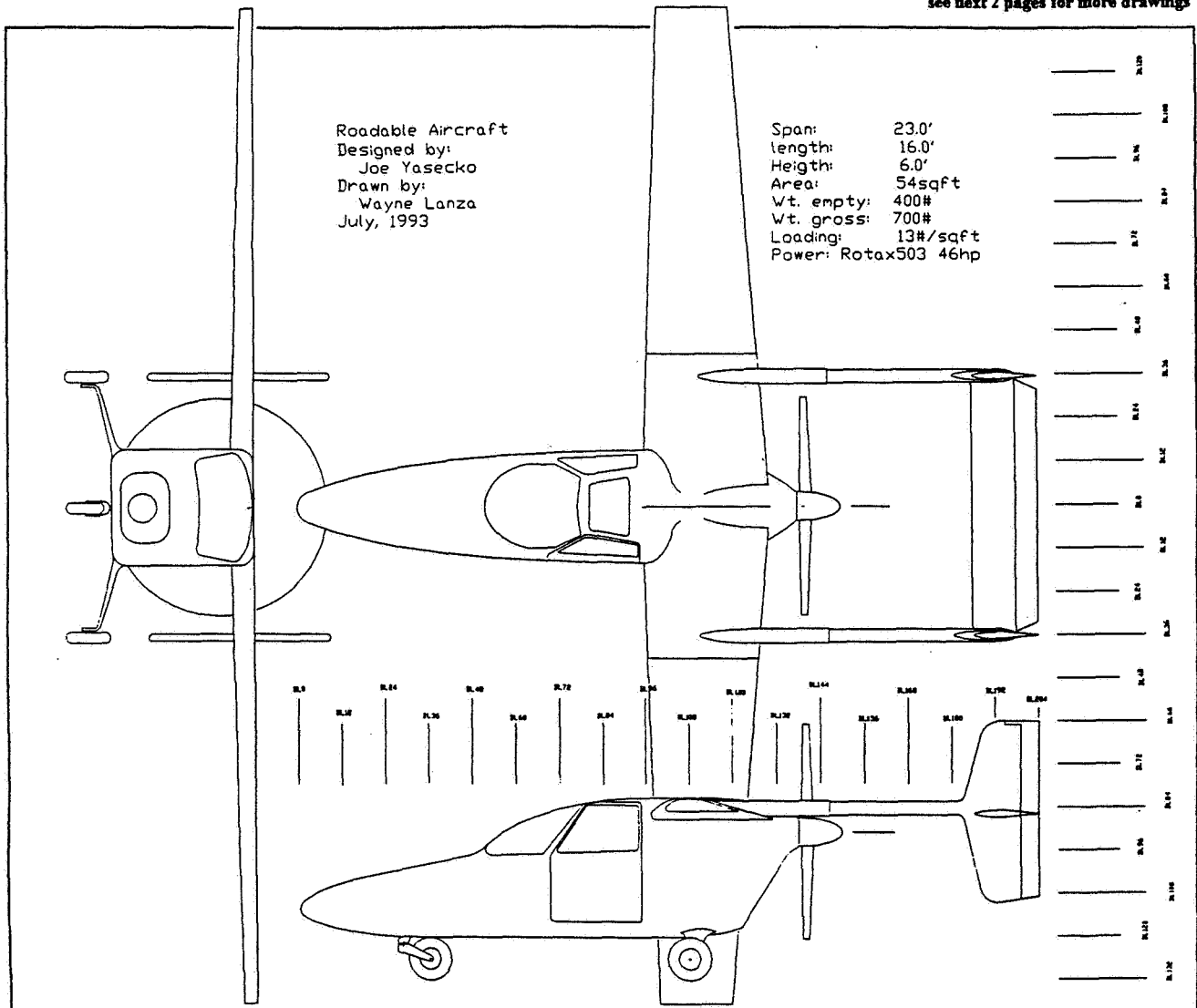
As the plans are currently drawn the airborne length is 17

feet. The tailbooms would retract about 3 feet for road use. Joe is concerned about the weight distribution of the of the vehicle in the ground mode. Because the majority of a tapered cantilever wing panel's weight is concentrated at the root, the folded wing does not move the CG forward very much.

The power plant will be a Rotax 503 of 46 to 52 horsepower.

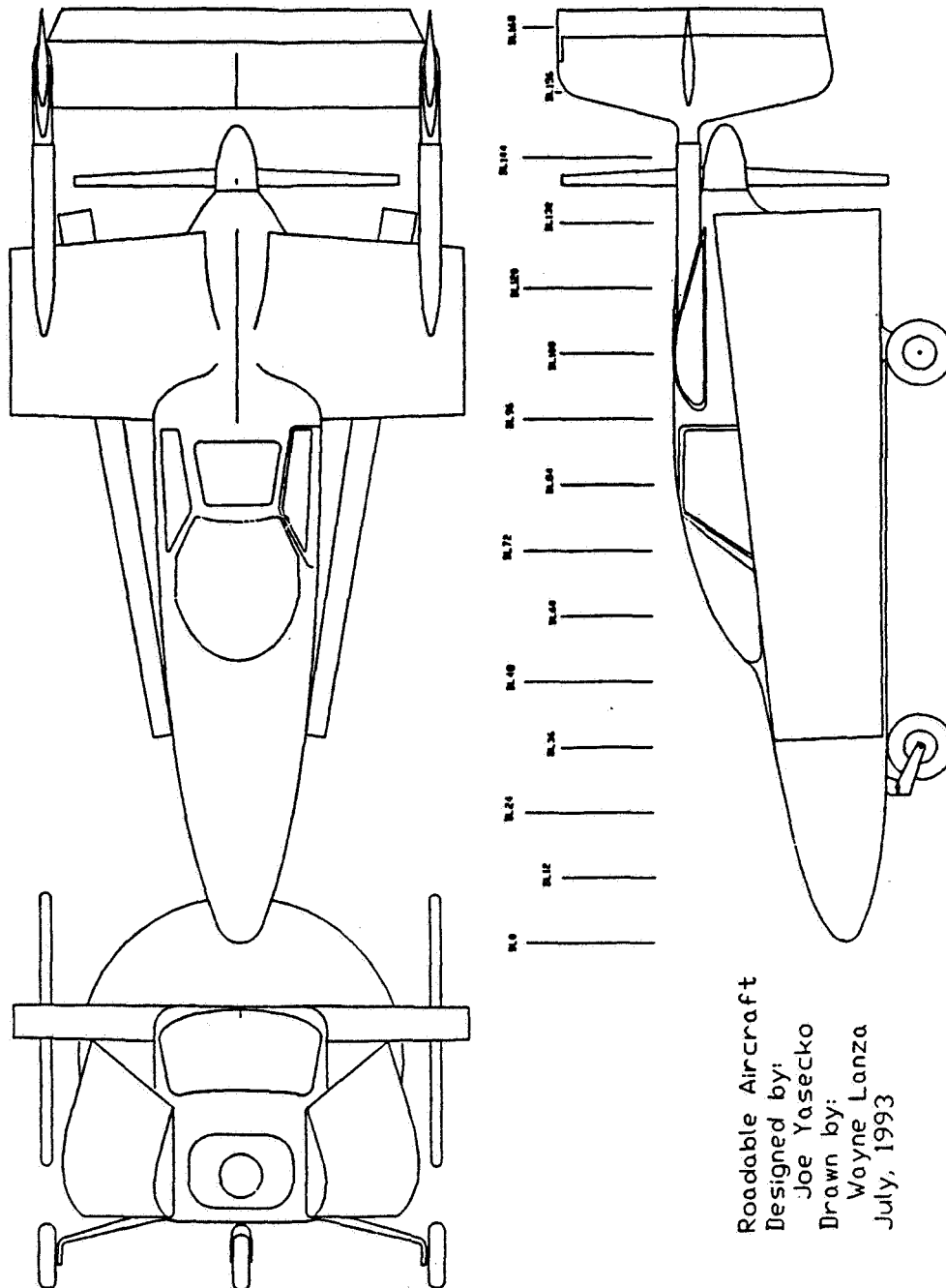
end of text

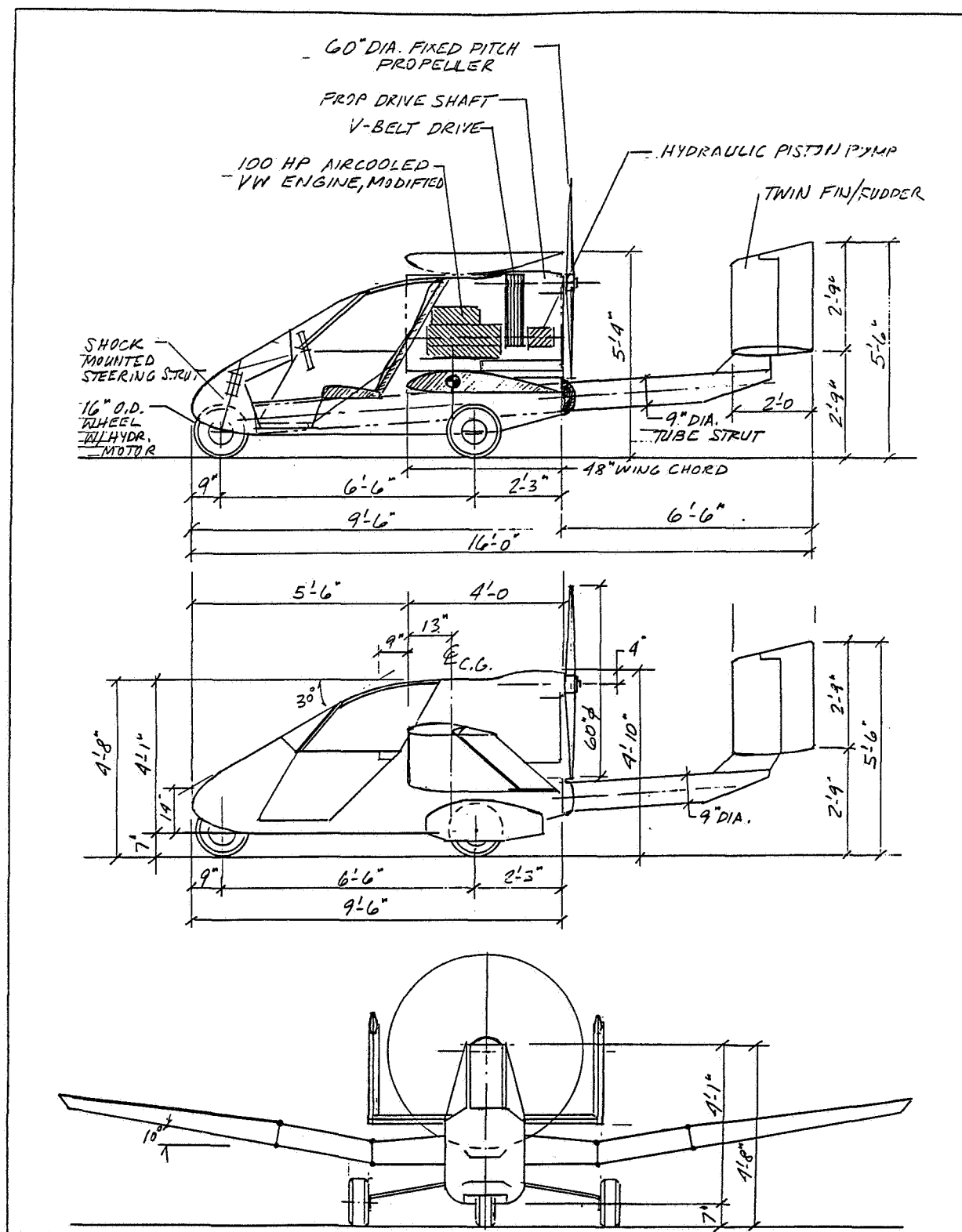
see next 2 pages for more drawings



Joe Yasecko

continued





Fourth in the series, the Aircar - 11. Also known as the Mini-Aircar 11.

New Technologies

Information

GPS and enhancements
Radio modem communications
Kalman filters

Structures

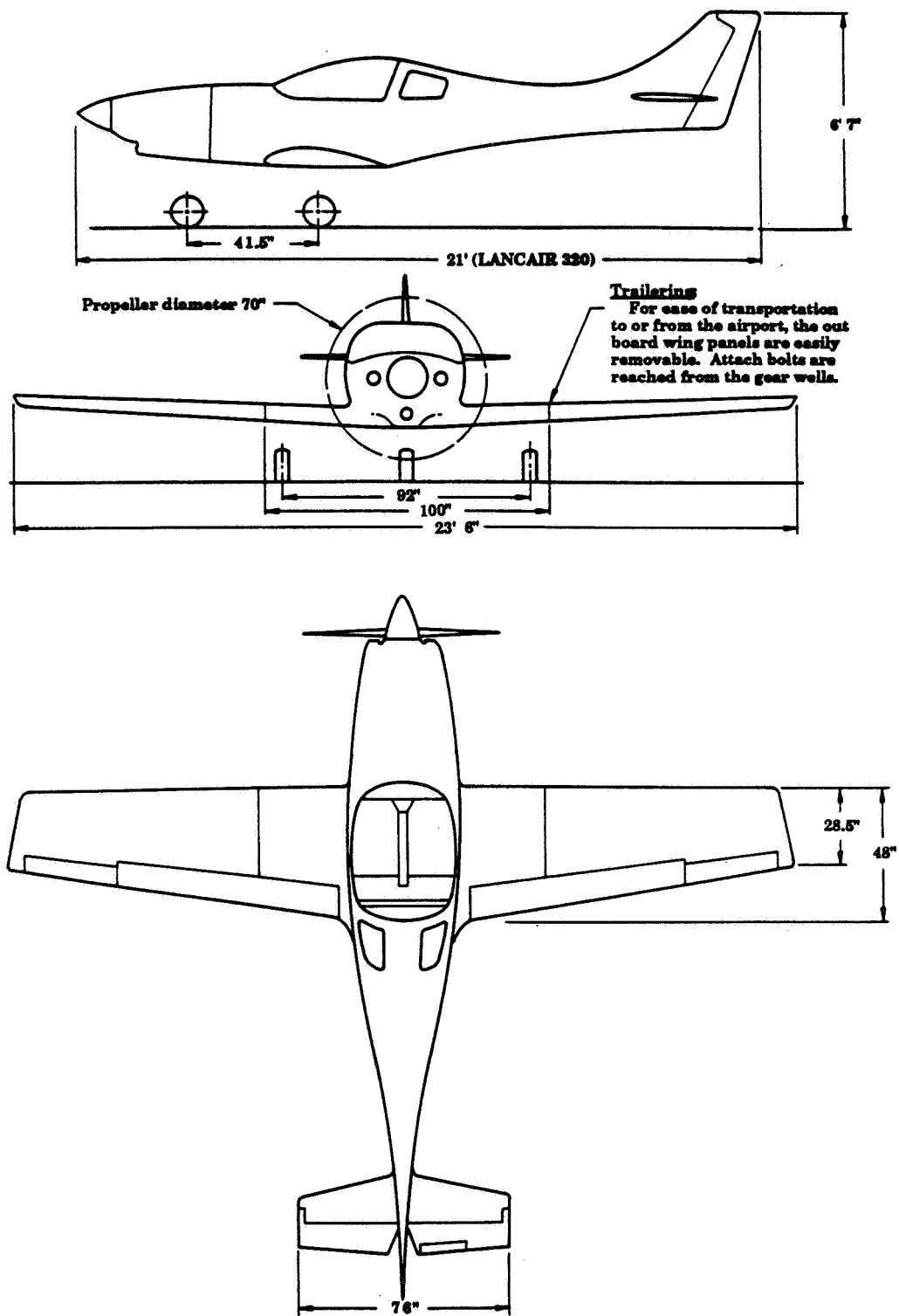
Advanced composite structures

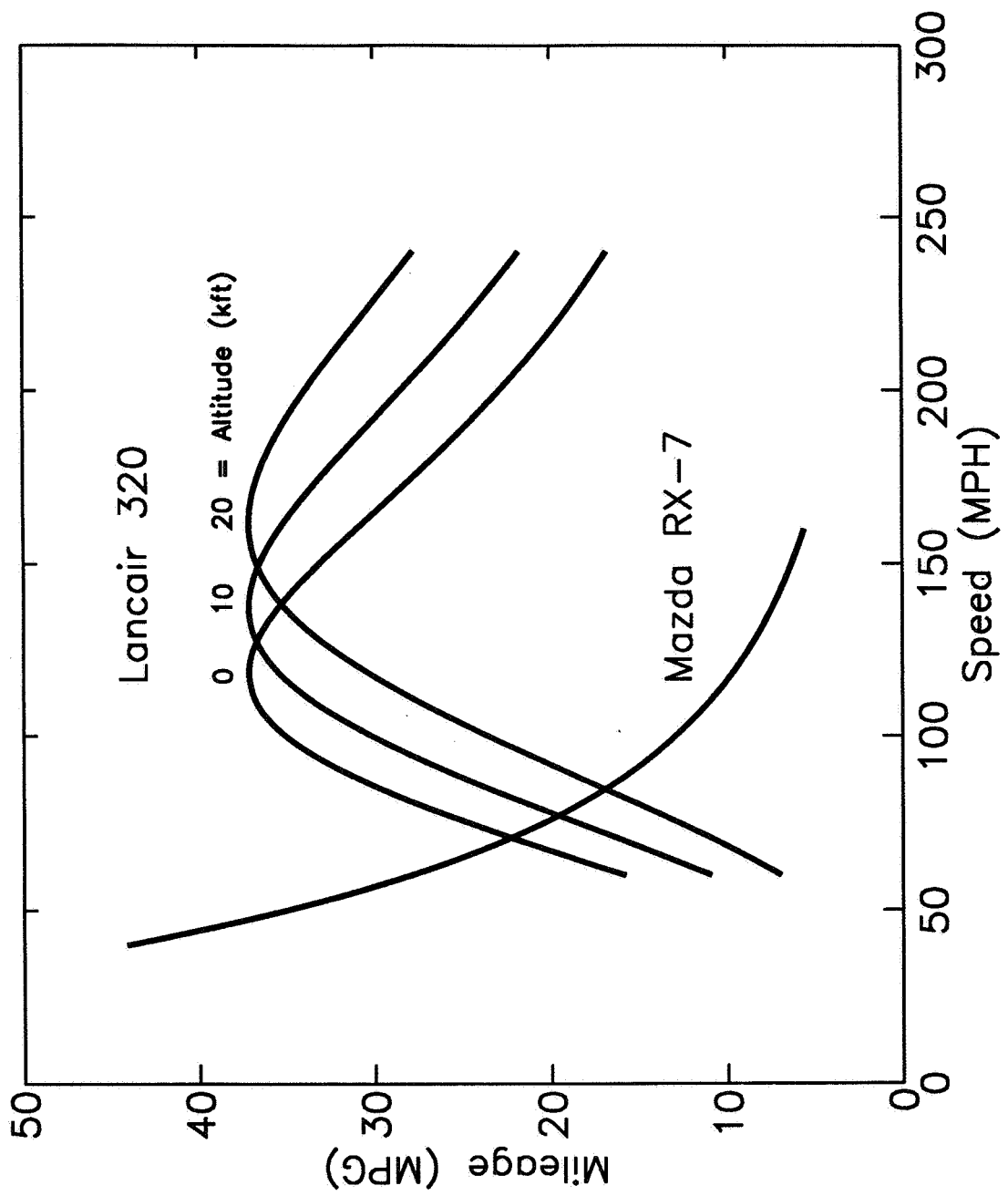
Propulsion

Electronic fuel and spark controls



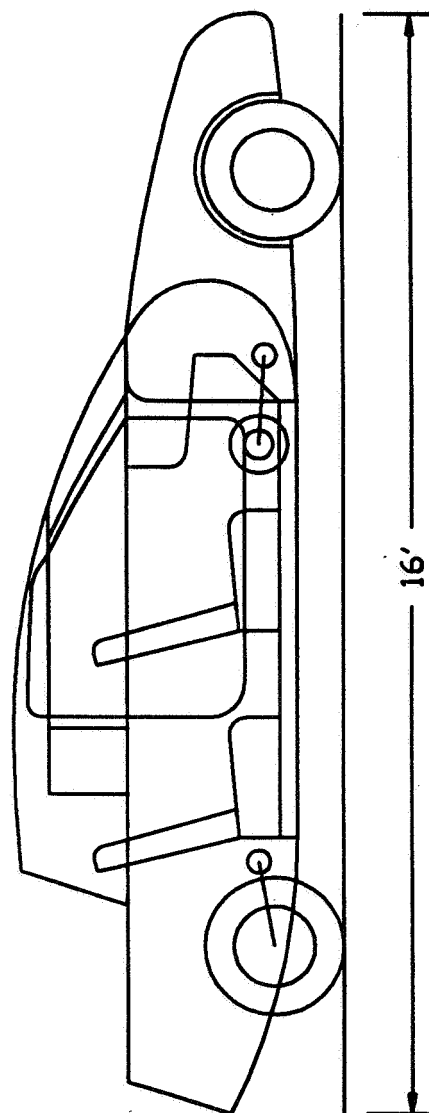
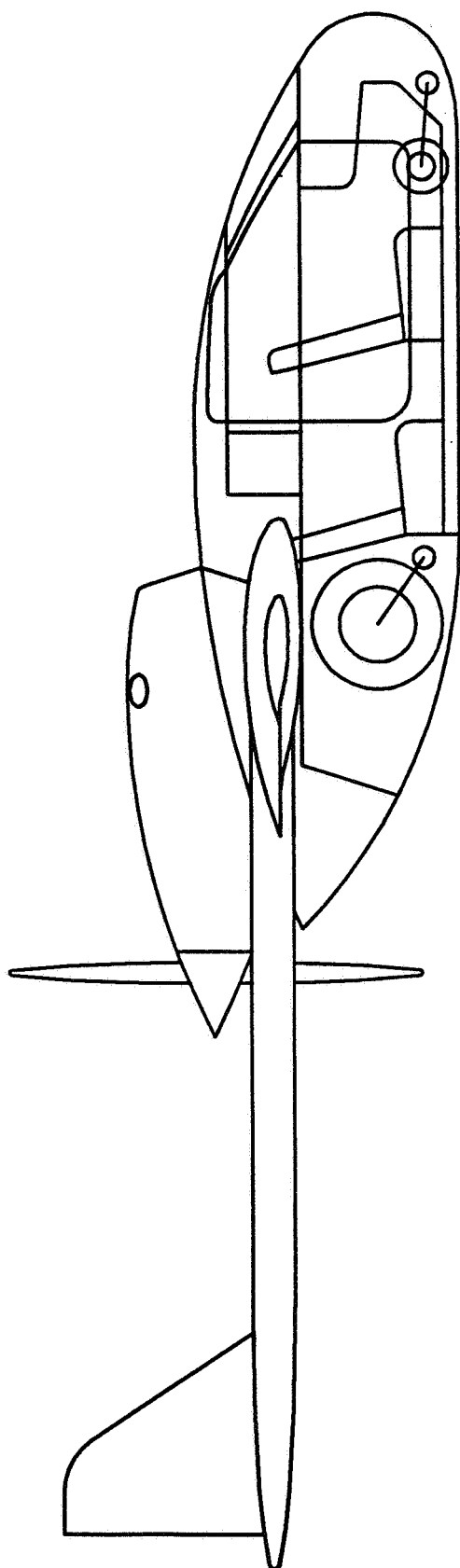
320 DIMENSIONAL VIEWS





PERFORMANCE ADVANTAGES OF AN AIRPLANE OVER AN AUTOMOBILE

Parameter	Mazda RX-7	Lancair 320	Airplane Advantage
ρ (slug/ft ³)	0.002378	0.001756	1.35
c (lb/hr/hp)	0.62	0.45	1.38
η	0.90	0.85	0.94
S_d (ft ²)	7.20	1.60	4.50
Rolling friction			1.18
Net airplane advantage			9.30



Starcar 3

Goals

- Precision control with differential GPS, including automatic landings.
- Informed use of automobile engine for flight.
- Practical transformation between automobile and airplane.

Feature

- Two seats with separate automobile and airplane controls.

Starcar 3 (Continued)

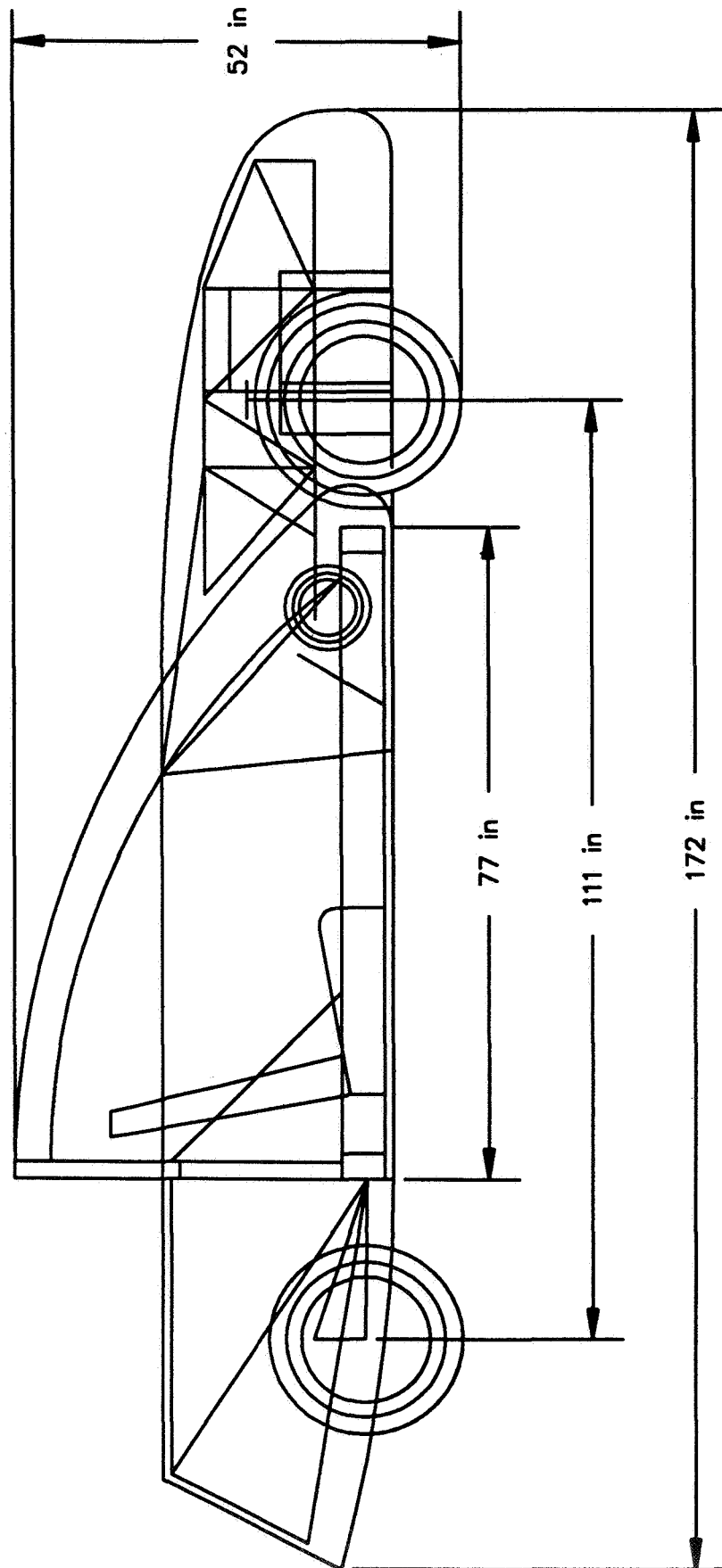
Specifications

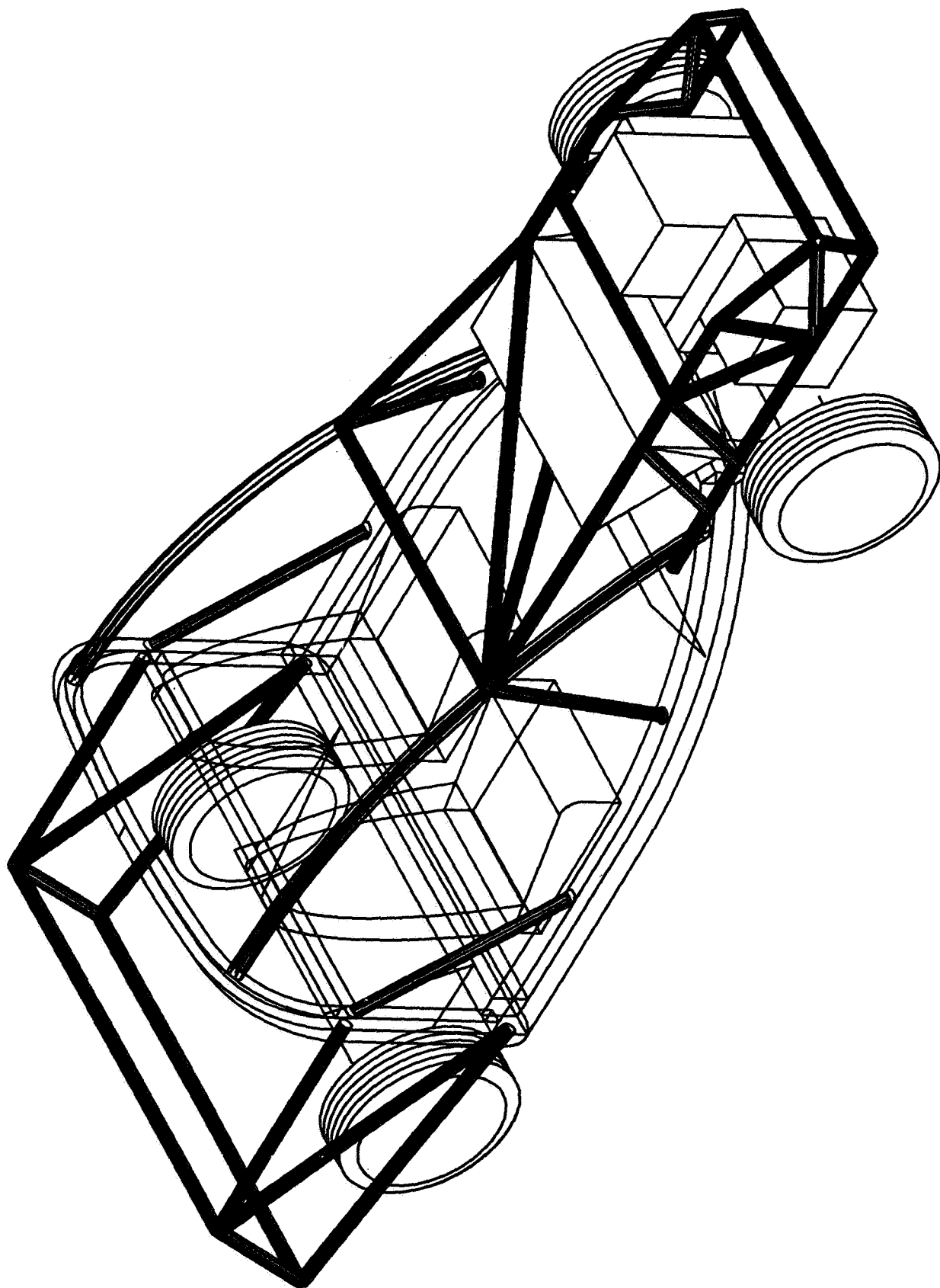
Span of 28 ft.

Gross weight of 2190 lbs as airplane.

Fuel economy of 21.6 mpg at 200 mph.

Top speed of 235 mph.



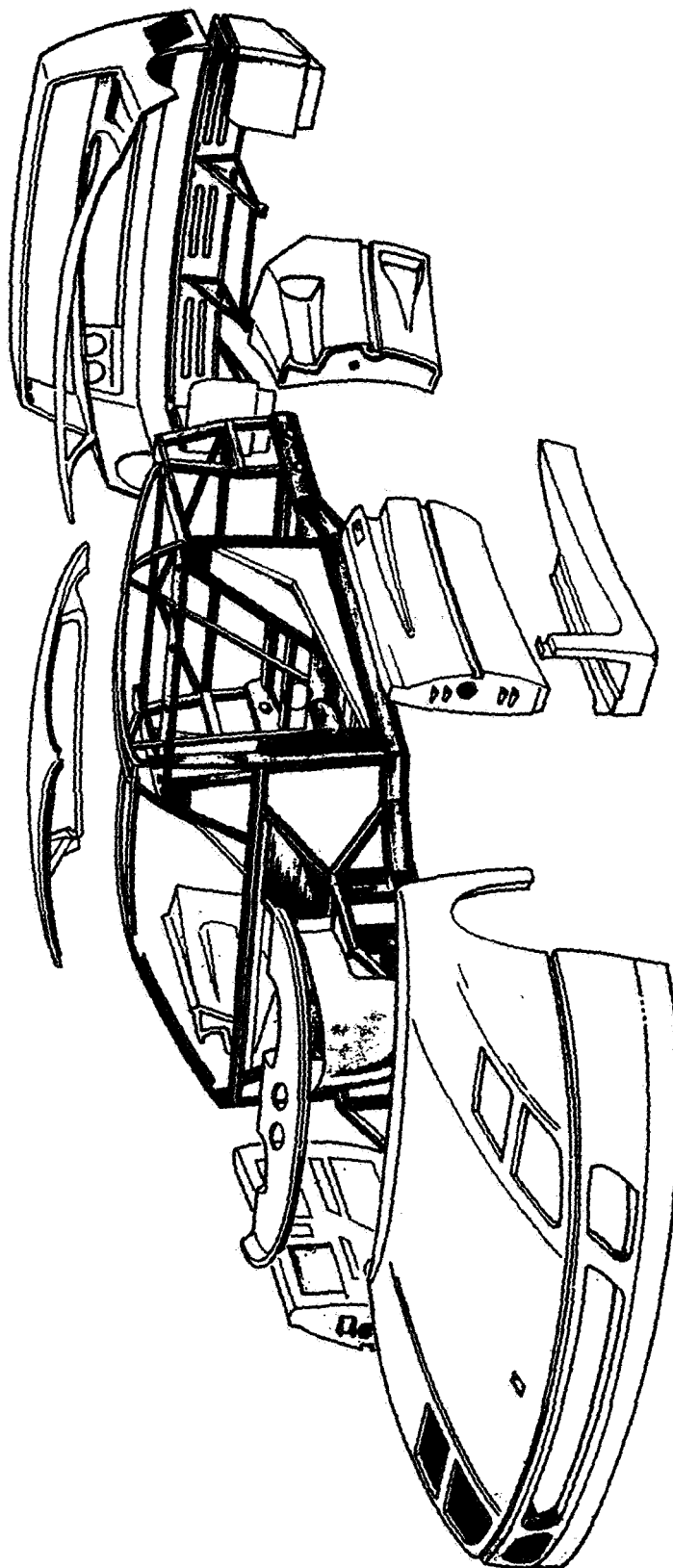


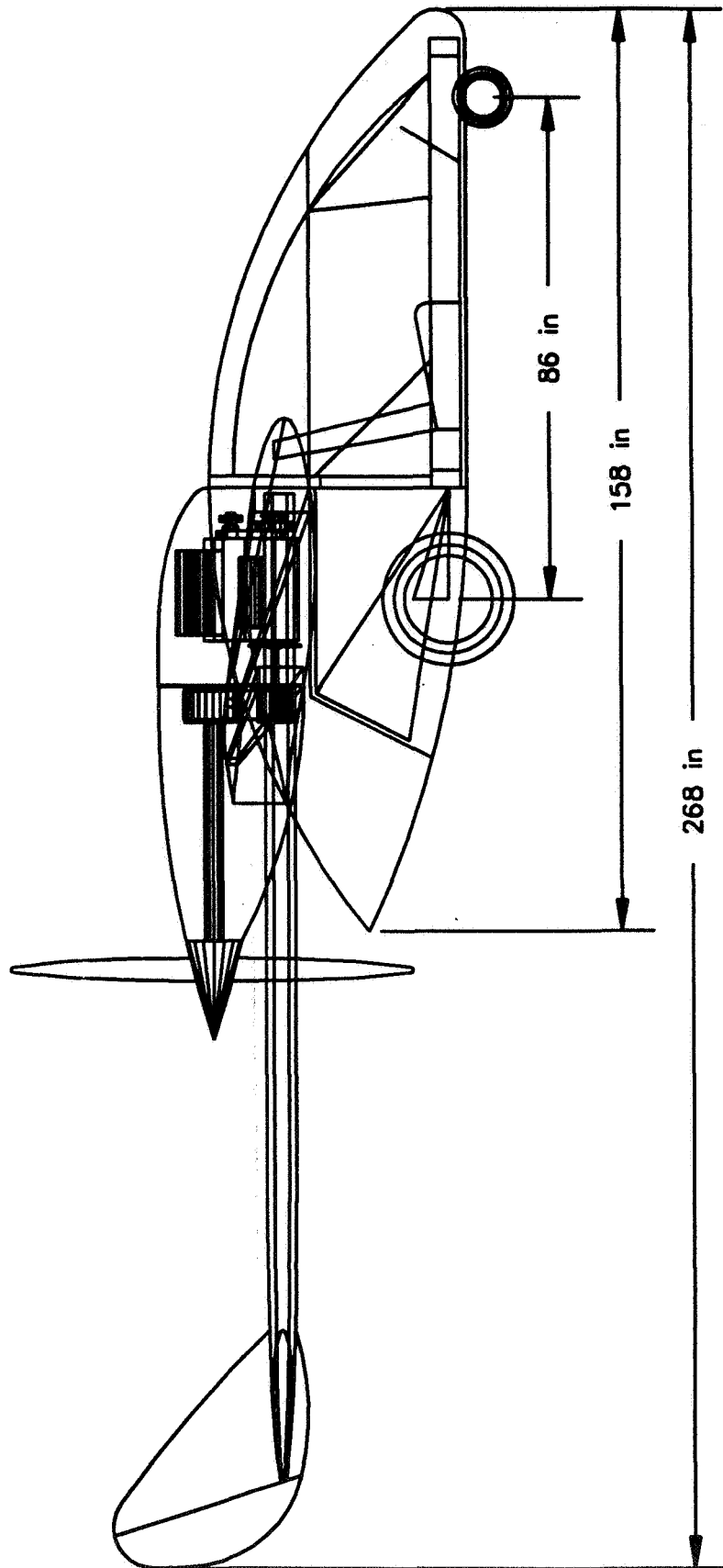
F40

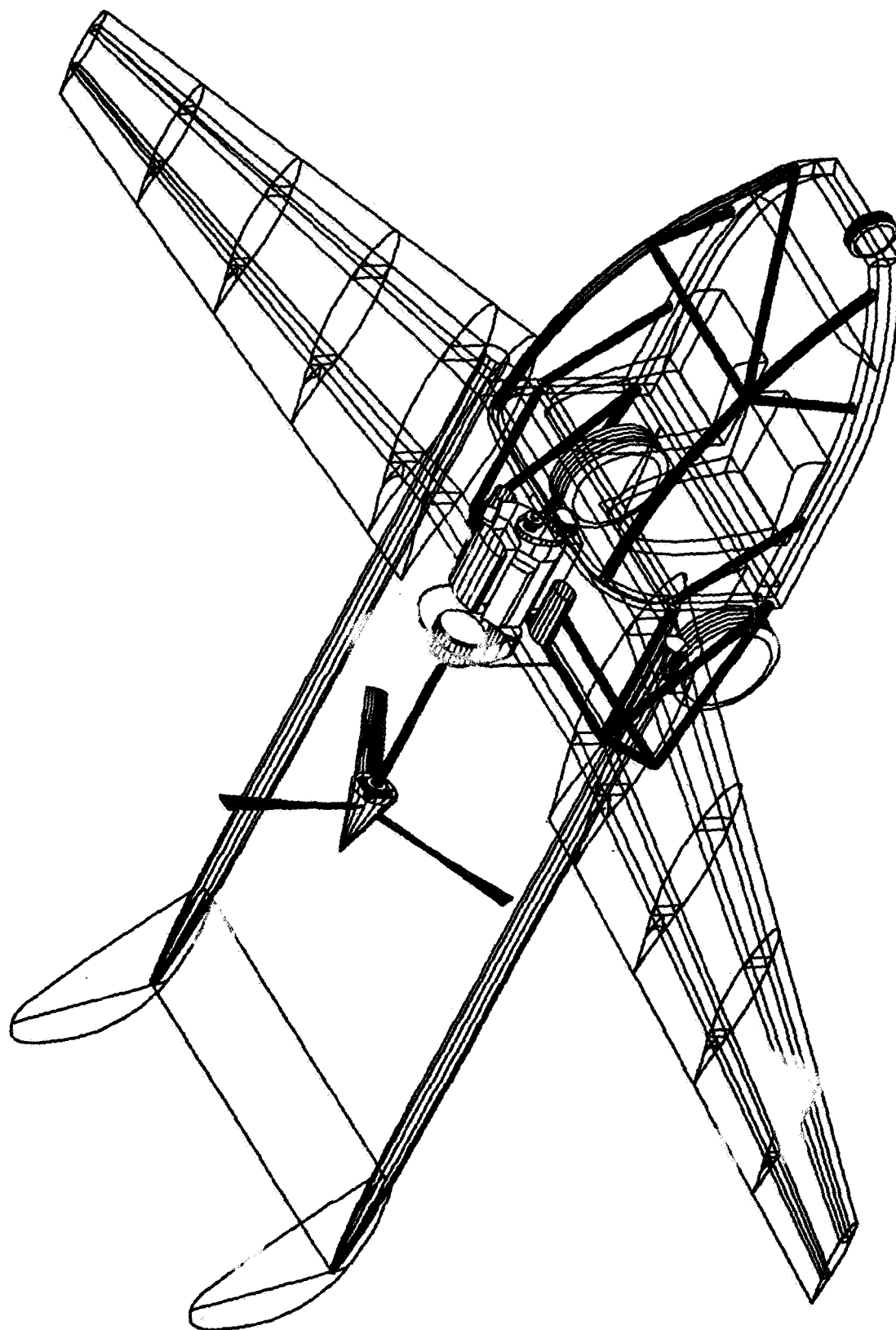
□ Materiale composito / Composition material / Matériau composite

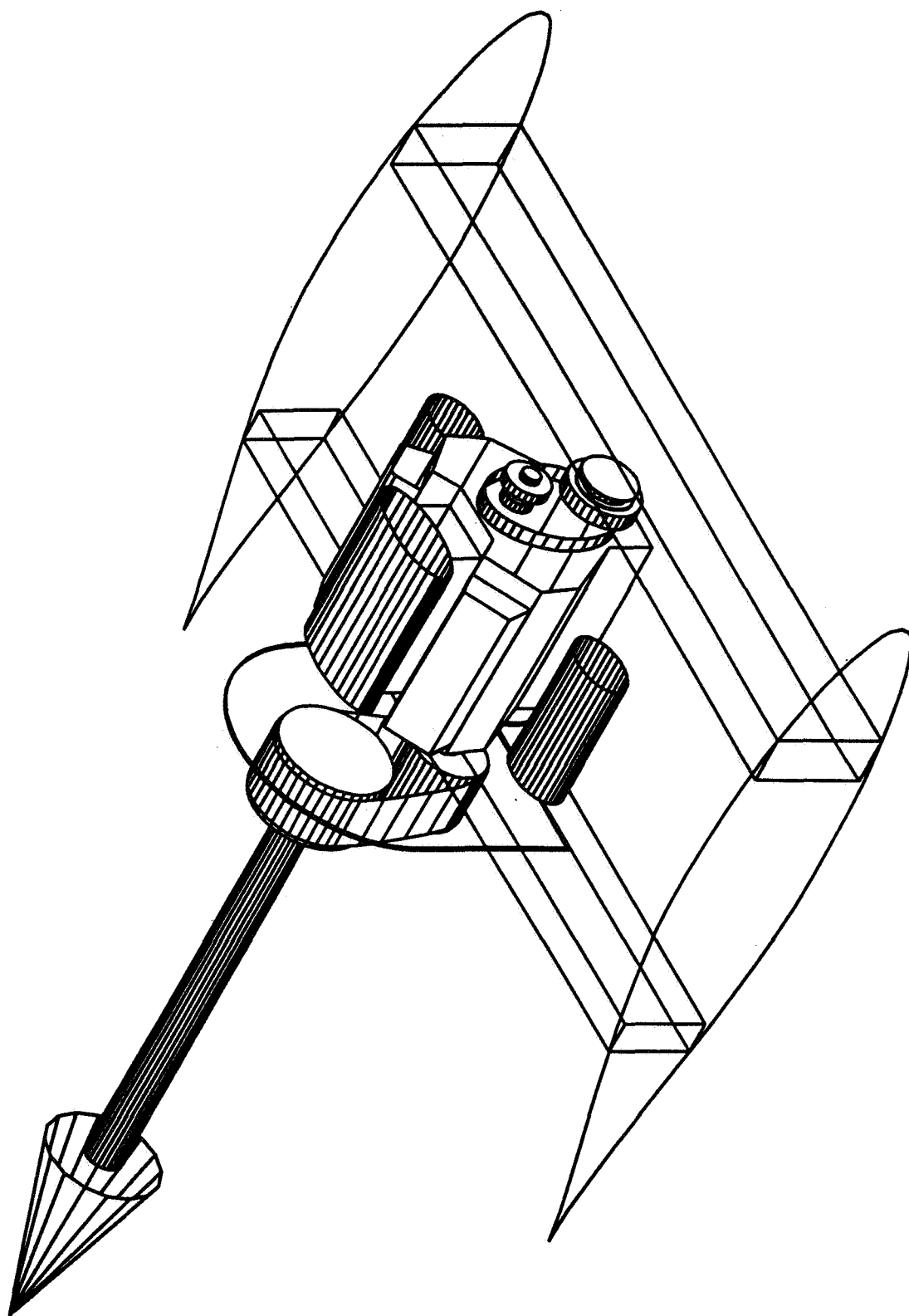
■ Traliccio in acciaio / Steel structure / Cadre en treillis en acier

■ Adesivo strutturale bicomponente / Dual component structural adhesive / Adhésif structural bicomposant









Conclusion and Goals

Conclusion

Flying cars are possible and have commercial potential.

The penalty for roadability is about 500 lbs.

Goals

Integrate an automotive engine with a dual-mode transmission.

Build a flying car similar to Starcar 3 but self-contained, with folding wings and telescoping tail booms.

omit

Session 3: Mass Transportation

<i>Aerodynamics of MAGLEV Trains</i>	213 -8
Dr. Joseph A. Schetz and Dr. James F. Marchman III	
<i>Magnetic Levitation Systems for Future Aeronautics and Space Research and Missions</i>	235 -9
Dr. Isaiah M. Blankson and John C. Mankins	
<i>Far Term Visions in Aeronautics</i>	261 -10
Dennis M. Bushnell	
<i>History, A Projection of the Future: A Rotary Wing Perspective</i>	297 -11
Robert J. Huston	
<i>Highly Nonplanar Lifting Systems</i>	331 -12
Dr. Ilan Kroo	
<i>The Application of Pneumatic Lift and Control Surface Technology to Advanced Transport Aircraft.</i>	371 -13
Robert J. Englar	
<i>The Future of Very Large Air Transport Vehicles: A Lockheed Martin Perspective</i>	399 -14
R. Steven Justice, Anthony P. Hays, and Ed L. Parrott	
<i>Evolution of the Revolutionary Blended-Wing-Body Subsonic Transport</i>	431 -15
Dr. Robert H. Liebeck, Mark A. Page, and Blaine K. Rawdon	
<i>Large Capacity Oblique All-Wing Transport Aircraft</i>	461 -16
Thomas L. Galloway, James Phillips, Mark Waters, and Robert Kennelly, Jr.	
<i>A Corporate Supersonic Transport (CST)</i>	491 -17
Randall Greene and Dr. Richard Seebass	

58-37
39473

Aerodynamics of Magnetic Levitation (MAGLEV) Trains

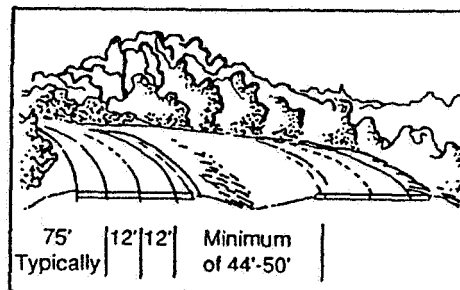
**Joseph A. Schetz
and
James F. Marchman III
Virginia Tech
Blacksburg, VA**

**Transportation Beyond 2000:
Engineering Design for the Future**

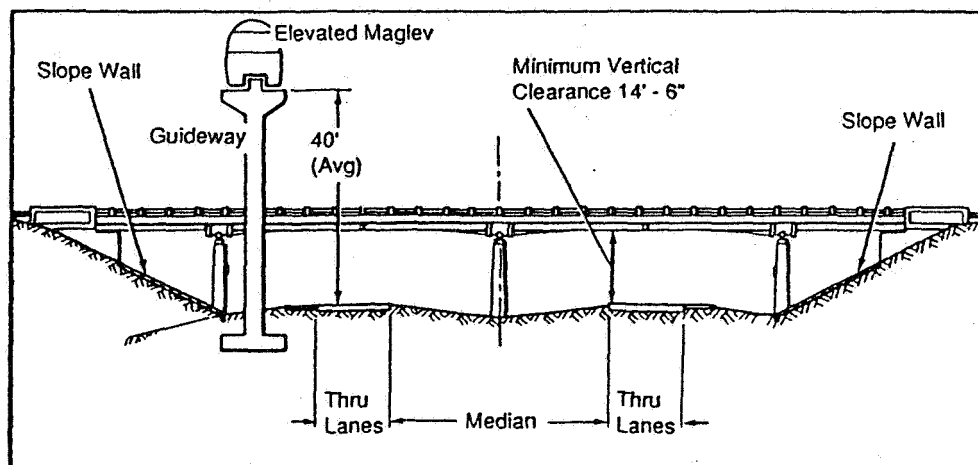
September 26-28, 1995

Track Arrangement

The track arrangement that is receiving the most consideration in the US is elevated as shown.



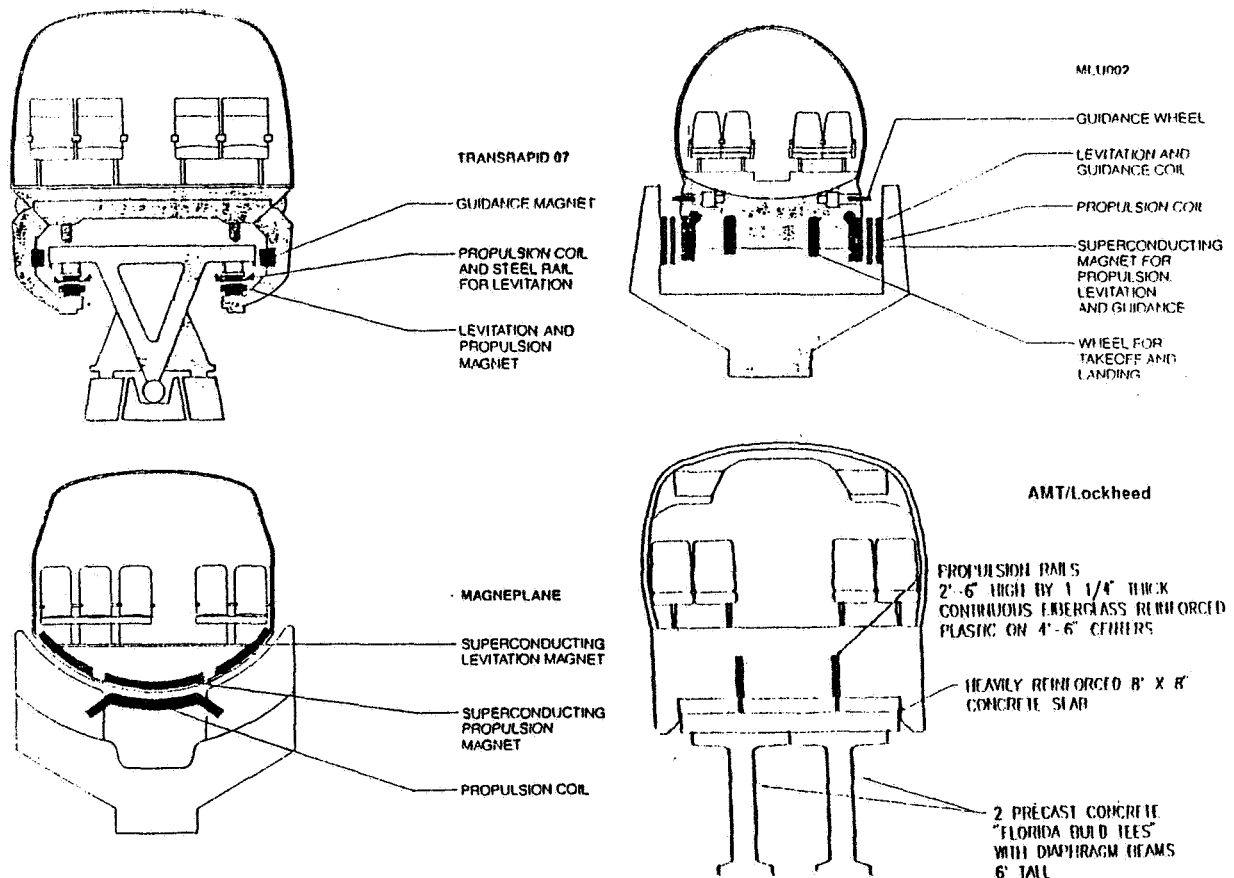
There's ample clearance on rural Interstates for Maglev construction along the median or the right of way.



Elevating the Maglev guideway provides adequate clearance over existing Interstate bridges and other structures.

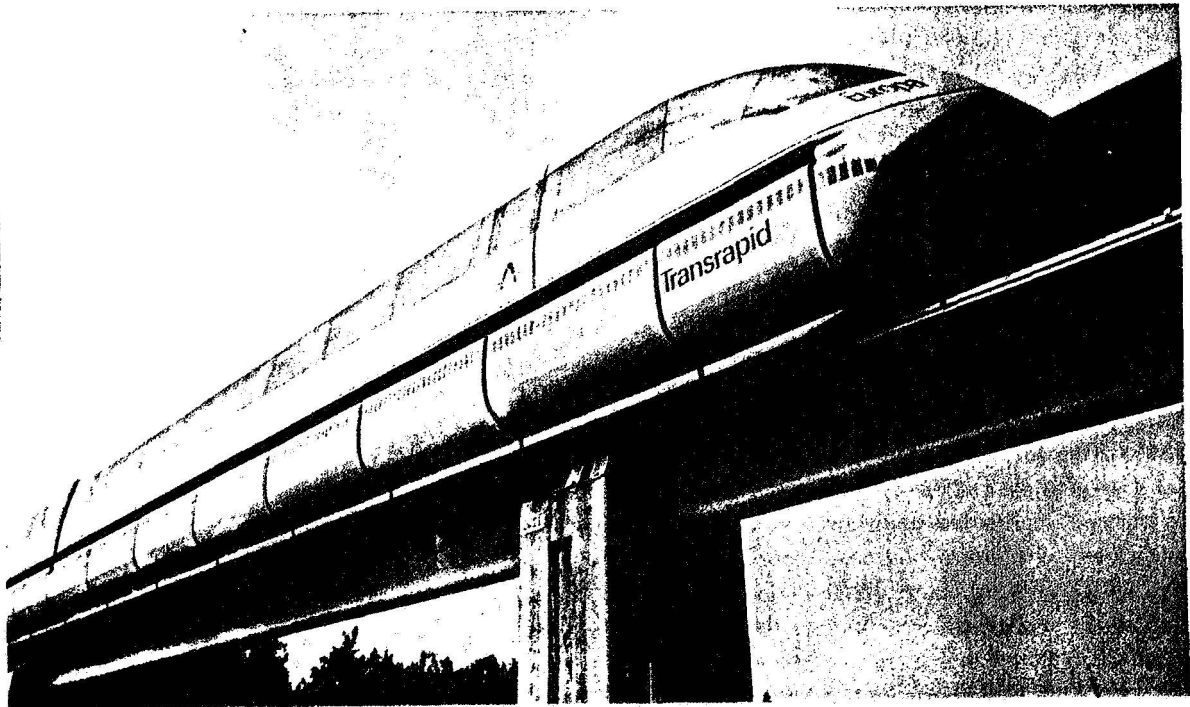
Magnetic Suspension Systems

The different systems that have been proposed have a large influence on vehicle configuration design.

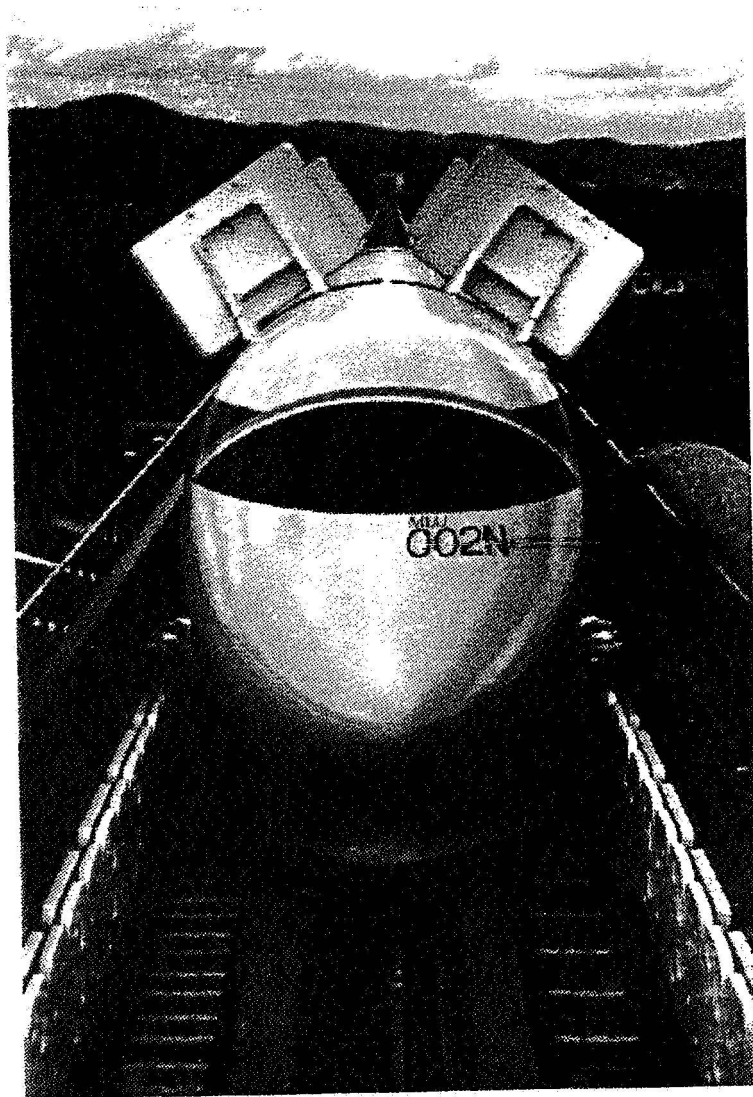


German Test Vehicle

There are ongoing test vehicle programs in Germany and Japan.

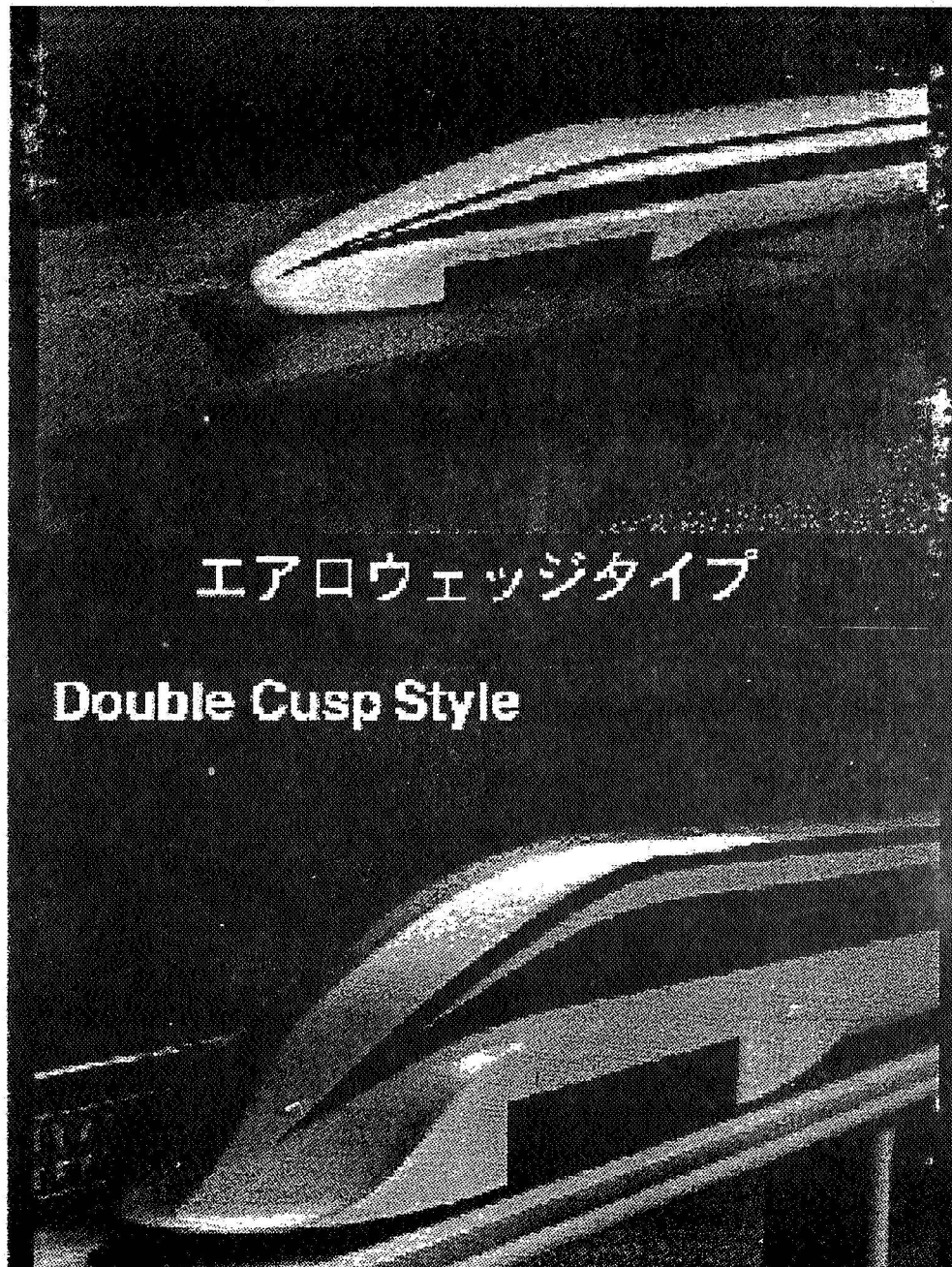


Japanese Test Vehicle



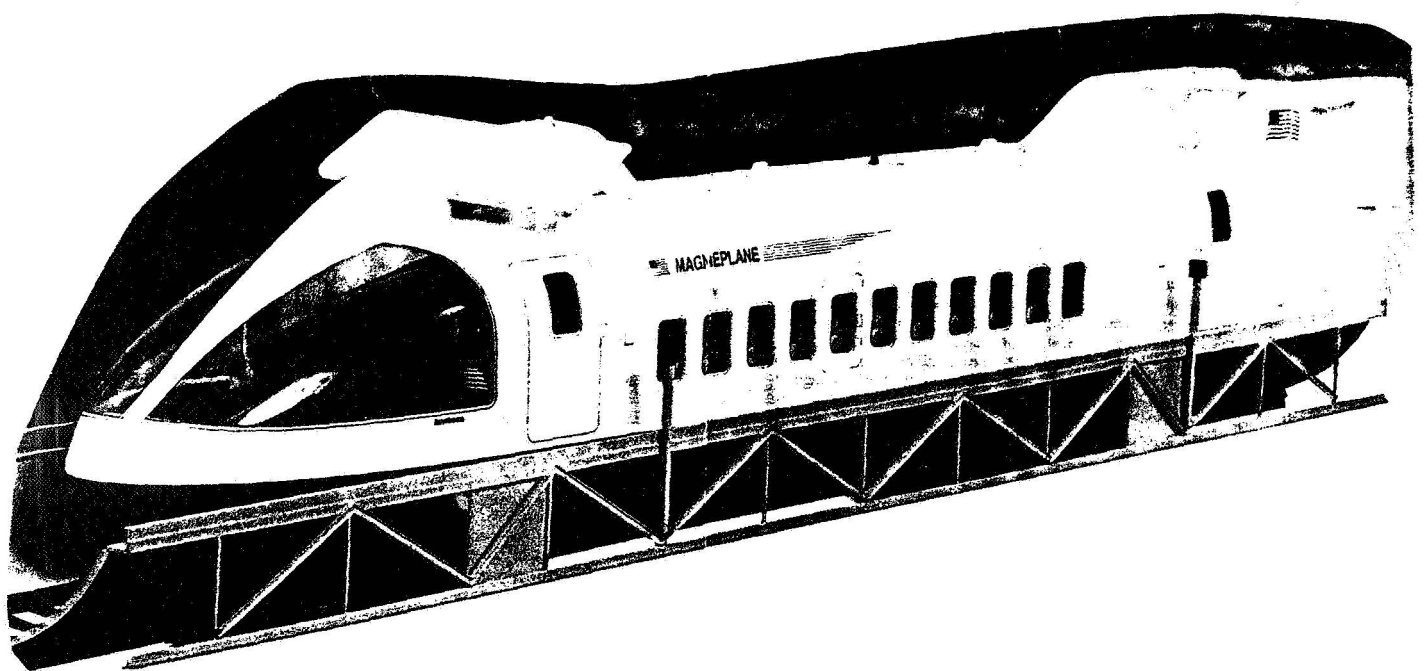
Proposed Japanese Designs

The Japanese have developed new designs to minimize aerodynamic forces, noise and tunnel entry/exit problems.

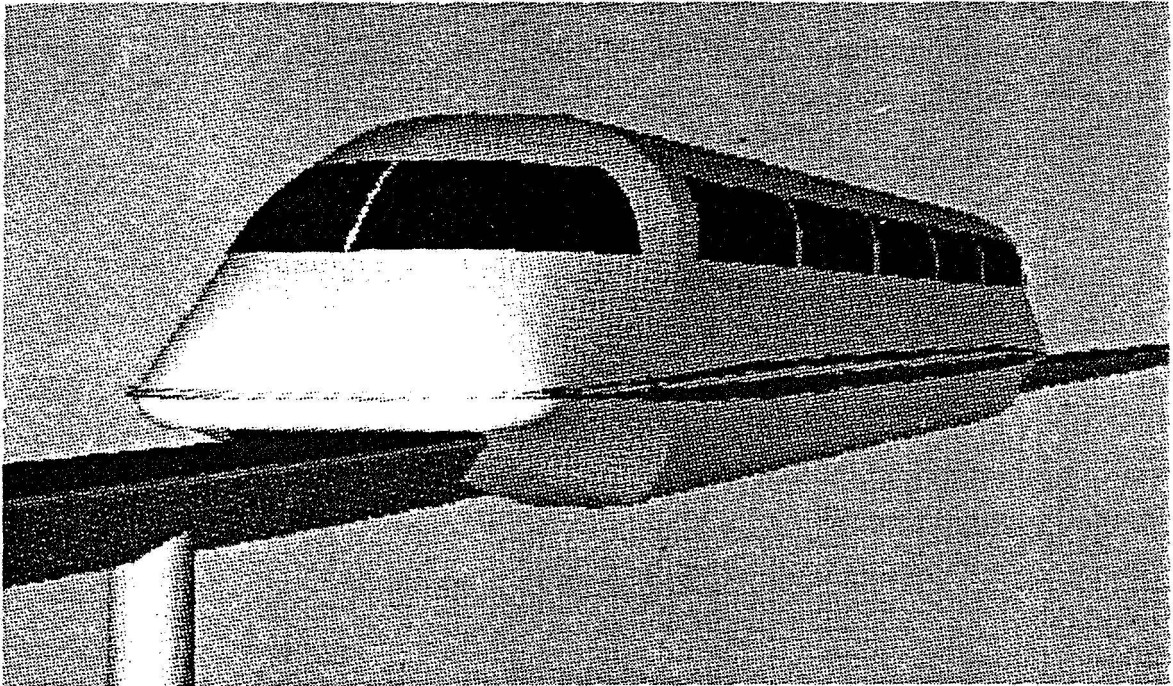


Proposed US Designs

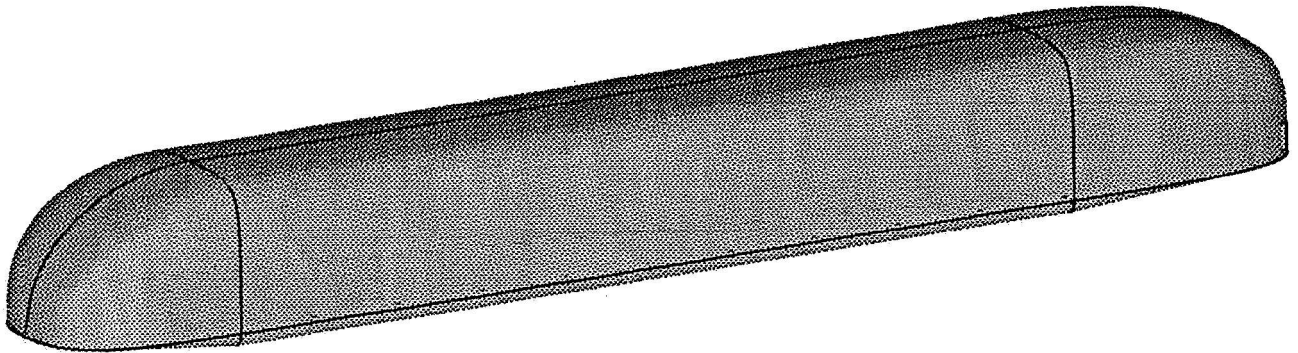
There are several US designs that have been proposed.



Grumman Designs



Lockheed Design for AMT



Need for Wind Tunnel Studies

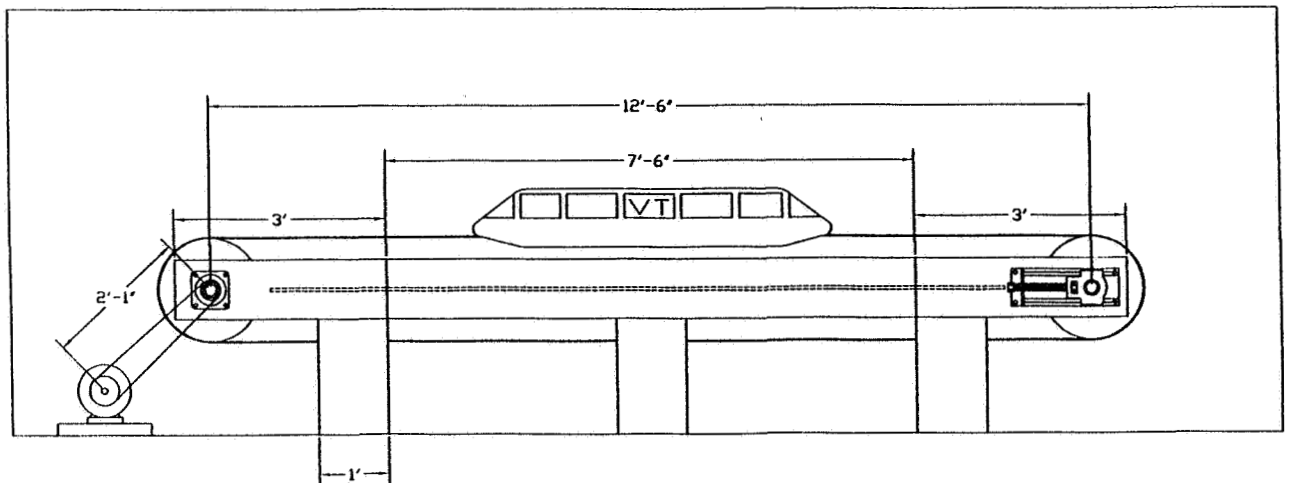
- + There is little relevant data in the literature
- + The analytical estimates for drag vary widely
- + CFD is unreliable and very expensive for 3D flows with separated regions

Wind Tunnel Tests of Maglev Vehicles

- + Model ground effect of track with a moving belt
- + Model clearance between elevated track and ground (approx. 3 diam.)
- + Parallel, uniform incoming flow to model accomplished with proper shrouding
- + Reynolds number simulation with a "trip" strip

Moving Belt System

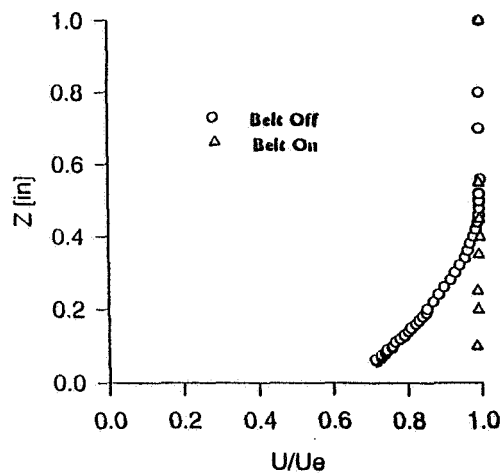
- + Use in *VT* 6 ft. X 6 ft. Wind Tunnel
- + Accommodate 6 ft.(long) X 1 ft.(diam.) model
- + Maximum belt speed



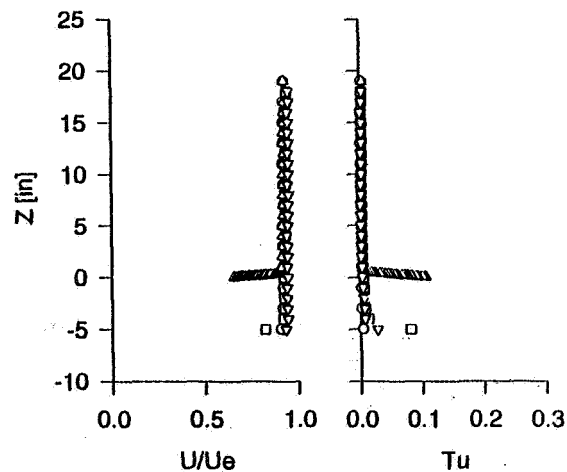
SHROUDING NOT SHOWN

Incoming Flowfield Verification

- + Hot-wire measurements at various locations above and around the belt
- + Mean-flow and turbulence profiles

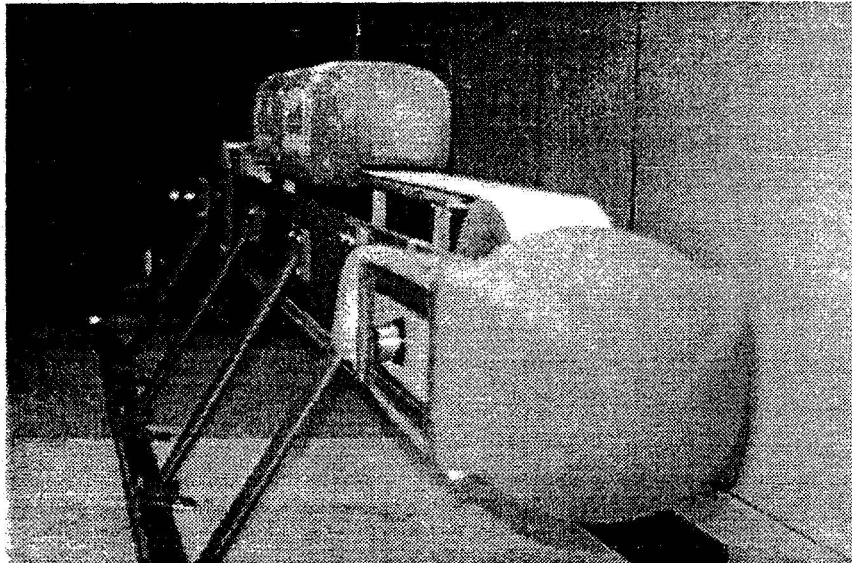


Belt Center Boundary Layer At Nose Location



Nose Location, Stationary Belt Region Velocity And Turbulence Profiles

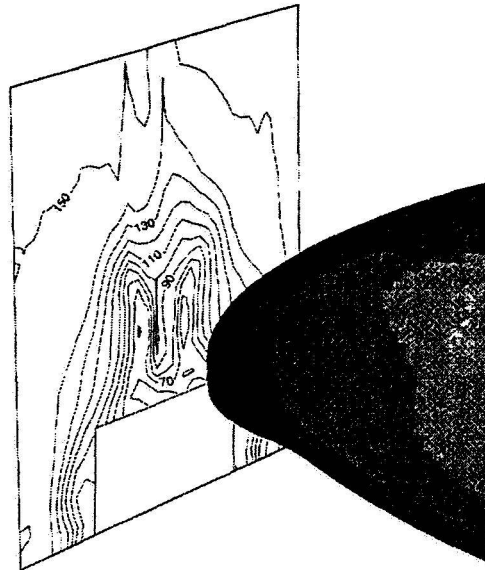
Northrop/Grumman Model in the Wind Tunnel with Moving Track



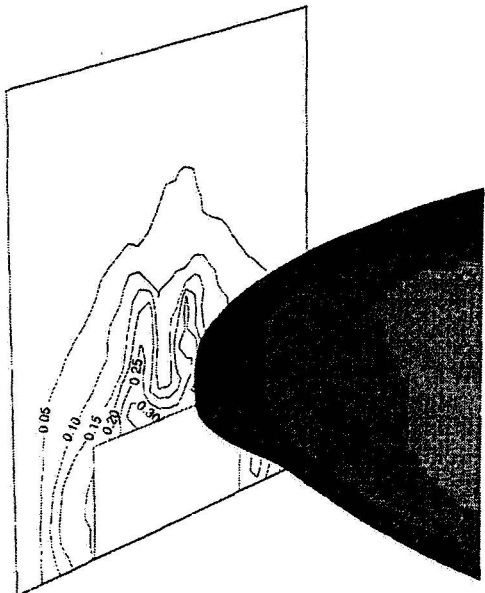
Experimental Methods

- + Force and Moment balance
- + Tuft surface flow observations
- + Hot-wire flowfield surveys
- + Surface pressure distributions
- + Skin friction gages

Typical Flowfield Surveys

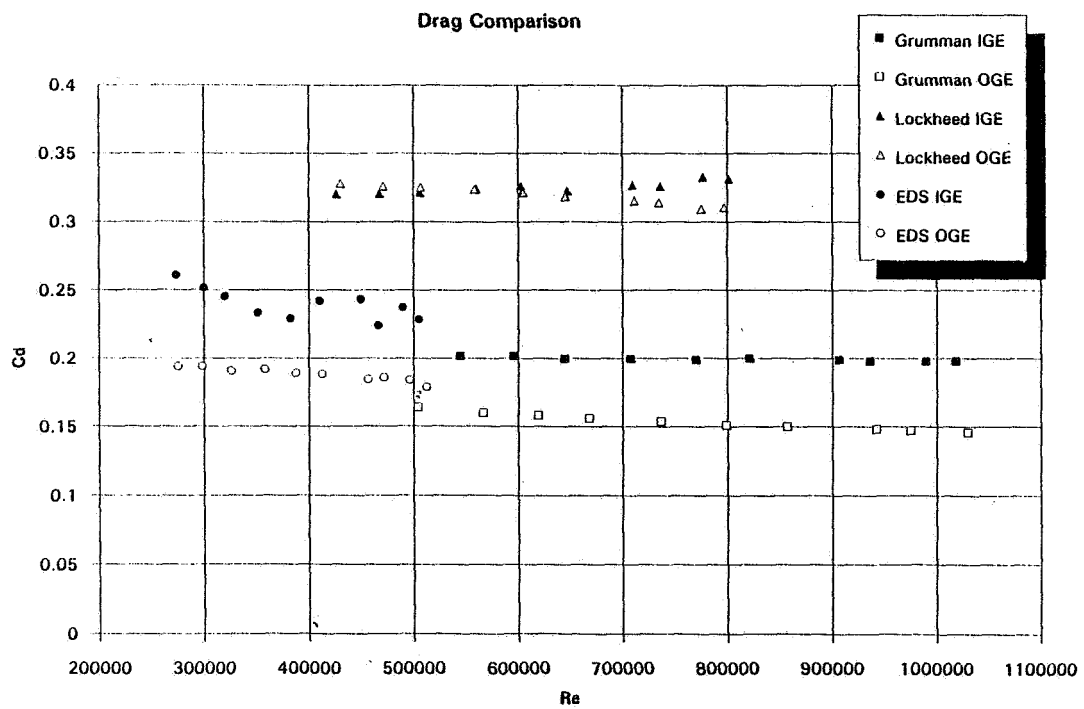


Velocity Contours Aft Of Tail

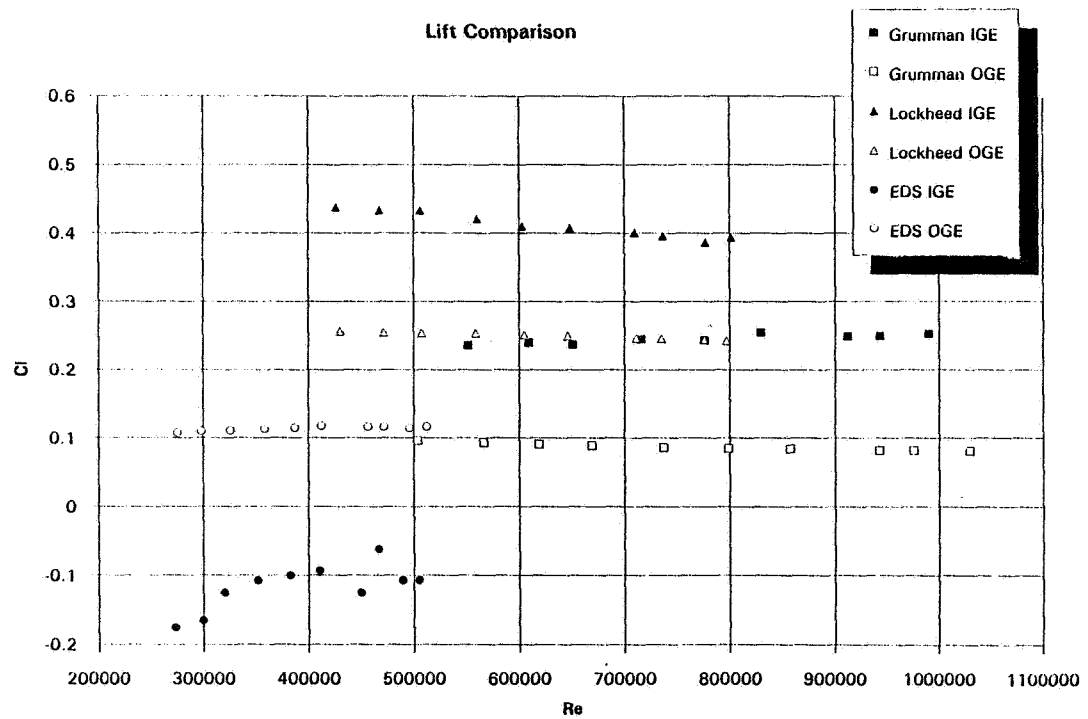


Turbulence Contours Aft Of Tail

Wind Tunnel Data



Wind Tunnel Data



MultiDisciplinary Design

Design Considerations

- ◆ Aerodynamics
- ◆ Structures
- ◆ Control
- ◆ Propulsion
- ◆ Cost
- ◆ Transportation utility

MultiDisciplinary Design

Aerodynamics

- ◆ Low Drag, Lift and Moment
- ◆ Low noise
- ◆ Cross winds
- ◆ Passing
- ◆ Tunnel entry/exit

MultiDisciplinary Design

Structures

- ◆ Load-bearing skin (like an airplane, not like a train)
- ◆ Weight
- ◆ Construction/materials
- ◆ Impact loads
- ◆ Unsteady aero loads

MultiDisciplinary Design

Cost/Shape

- ◆ Weight
- ◆ Shape complexity and tolerances
- ◆ Construction/materials
- ◆ Conventional rail cost info NG
- ◆ Some MAGLEV cost info available
- ◆ Use small transport plane cost info

**Office of
Aeronautics**

**NASA HEADQUARTERS
WASHINGTON, DC**

MAGNETIC LEVITATION SYSTEMS FOR FUTURE AERONAUTICS AND SPACE RESEARCH AND MISSIONS

Presentation at Workshop

**TRANSPORTATION BEYOND 2000:
TECHNOLOGIES NEEDED FOR ENGINEERING DESIGN**

**NASA Langley Research Center
Hampton, VA**

SEPTEMBER 26 - 28, 1995

**DR. ISAIAH M. BLANKSON and
MR. JOHN C. MANKINS
Critical Technologies Division
Hypersonics Research
Code RR**

59-37
39474

**TO BE PRESENTED AT LANGLEY ADVANCED TRANSPORTATION
WORKSHOP, September 26 -28**

**MAGNETIC LEVITATION SYSTEMS FOR FUTURE
AERONAUTICS AND SPACE RESEARCH AND MISSIONS**

Isaiah M. Blankson and John C. Mankins
Office of Aeronautics and Office of Advanced Concepts
NASA Headquarters
Washington, D.C.

ABSTRACT

The objectives, advantages, and research needs for several applications of superconducting magnetic levitation to aerodynamics research, testing, and space-launch are discussed. Applications include very large-scale magnetic balance and suspension systems for high alpha testing, support interference-free testing of slender hypersonic propulsion/airframe integrated vehicles, and hypersonic maglev. Current practice and concepts are outlined as part of a unified effort in high magnetic fields R&D within NASA. Recent advances in the design and construction of the proposed ground-based Holloman test track (rocket sled) that uses magnetic levitation are presented. It is projected that ground speeds of up to Mach 8 to 11 at sea-level are possible with such a system. This capability may enable supersonic combustor tests as well as ramjet-to-scramjet transition simulation to be performed in clean air. Finally a novel space launch concept (Maglifter) which uses magnetic levitation and propulsion for a re-usable "first stage" and rocket or air-breathing combined -cycle propulsion for its second stage is discussed in detail. Performance of this concept is compared with conventional advanced launch systems and a preliminary concept for a subscale system demonstration is presented.

OUTLINE OF PRESENTATION

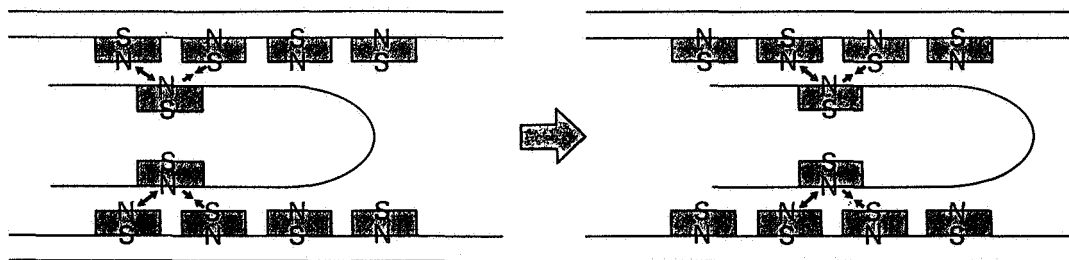
- **MAGNETIC LEVITATION R & D AT NASA**
 - Rationale for infrastructure building
- **APPLICATIONS OF MAGNETIC LEVITATION**
 - **MSBS**
 - **HOLLOMAN AFB TEST TRACK UPGRADE**
 - **MAGLIFTER / LUNATRON**
- **MASS TRANSPORTATION - - “MAGLEV”**
(airplanes flying in extreme ground effect)
 - **TECHNOLOGY NEEDS**
 - **RECENT DEVELOPMENTS IN JAPAN**

超電導リニアモーターカー・マグレブの原理 Principles of superconducting linear motor car MAGLEV

推進の原理

Principle of propulsion

磁石どうしの反発力と吸引力を利用して車両(超電導磁石)を推進させます。ガイドウェイの両側の側壁に並べられた推進用のコイルに、変電所から電流(3相交流)を流すと、ガイドウェイに移動磁界が発生します。車上の超電導磁石がこれに引かれたり、押されたりして車両は進みます。



A repulsive force and an attractive force induced between the magnets are used to propel the vehicle (superconducting magnet). The propulsion coils installed on the side walls on both sides of the guideway are energized by the three-phase alternating current from a substation, creating a shifting magnetic field on the guideway. The on-board superconducting magnets are attracted and pushed by the shifting field, propelling the Maglev vehicle.

磁気浮上の原理

Principle of magnetic levitation

●上下の支持

走行路となるガイドウェイの側壁内側には、8の字の形をした浮上用コイルが取り付けられています。このコイルの中心から数cm下側を車上の超電導磁石が高速で通過すると、コイルに電流が誘起されて一時的に電磁石となり、超電導磁石を押し上げる力(反発力)と、引き上げる力(吸引力)が発生し、車両を浮上させます。

●Vertical suspension

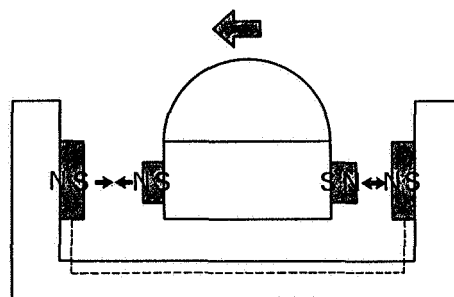
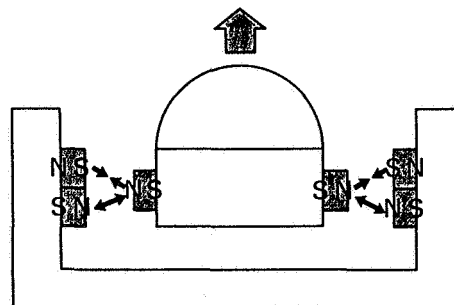
The "8" figured levitation coils are installed on the side walls on the guideway. When the on-board superconducting magnets pass at a high-speed several centimeters below the axes of these coils, an electric current is induced within the coils, making them act as electromagnets temporarily. As a result, the forces which push the superconducting magnet upwards and ones which pull them upwards act simultaneously, thereby levitating the Maglev vehicle.

●左右の案内

向かい合う浮上コイルは、走行路の下を通してループになるように繋がれています。走行中の車両(超電導磁石)が左右どちらかに偏ると、このループに電流が誘起されて、車両が近づいた方の浮上コイルには反発力が、車両が離れた方の浮上コイルには吸引力が働きます。このようにして、走行中の車両は常にガイドウェイの中央を走行することになります。

●Lateral guidance

The levitation coils facing each other are connected under the guideway, constituting a loop. When a running Maglev vehicle, that is, a superconducting magnet, displaces laterally, an electric current is induced in the loop, resulting in a repulsive force acting on a levitation coil near the car and an attractive force acting on another levitation coil farther apart from the car. Thus, a running car is always located at the center of the guideway.



MAGNETIC LEVITATION R&D at NASA

- In recent years, NASA and VPI (Virginia Polytechnic Institute) have provided support to the National Maglev Initiative (NMI) in the Department of Transportation's Federal Railroad Administration (FRA)
 - Support has been limited in scope, focusing on aerodynamics analyses of alternate maglev vehicle configurations
 - Other aeronautical technologies (structures, stability and control, noise, etc) are applicable
- Independently, NASA personnel have also examined various concepts and applications of magnetic levitation and related technologies for Agency purposes
 - **Wind tunnel model magnetic suspension and balance systems (MSBS) applications**
 - Magnetic bearings (superconducting and rare earth magnet) applications
 - High temperature superconductor materials and manufacturing (e.g., wire)
- Building on past studies, during the past 1.5 years, an intensive ad hoc examination has been conducted of the possibilities for application of maglev for space launch (i.e., the 'MagLifter' concept)
 - **The "MagLifter" concept:** Studies have focused on rocket-propelled vehicles
 - Potential applications include launch of small, medium and large Earth to Orbit (ETO) vehicles (Rocket, Airbreathing and Hybrid) as well as launch of hypersonics research X-vehicles)
 - **Coordination with USAF on the planned maglev upgrade of the high speed rocket-sled test track at Holloman AFB(a potential capability Mach 11+ using Maglev)**

Rationale for Maglev at NASA

NASA Systems-Level Space Opportunities

- Small Earth-to-Orbit Transportation (“Mark II” Catapults)
- Large Earth-to-Orbit Transportation (“Mark III” Catapults)
- Others

Dual-Use Technology Commercialization Systems-Level Opportunities — Aero/Space

- Maglev Ground Transportation
- Others

NASA Systems-Level Aeronautics Opportunities

- Hypersonics Research X-Vehicle Launcher (“Mark II” Catapult)
- Magnetic Suspension & Balance
- Hypersonic Test Track Research
- Others

Dual-Use / NASA Secondary Applications

- Magnetic Bearings (e.g., pumps, CMGs)
- Superconducting Materials Components (e.g., wire)
- Power Systems (distribution, storage, etc.)
- Potential Other Government Applications
- Others

Potential Impact of the Introduction of High-Temperature Superconductors

- High-Temperature (high 'Tc') superconductors could have major impacts in the areas of:
 - Cryogenics
 - Thermal stability of superconductor systems
 - Wire manufacturing and design
 - Vehicle magnetic shielding
 - System service and maintenance
- High Tc superconductors may also have moderate impacts in the areas of:
 - Levitation and guidance systems
 - System stress and fatigue effects
 - Vehicle structure and suspension
 - Guideway system design trades/choices (e.g., power; curves; track type)
 - Design-Level issues (capital costs, operating costs, human factors)

Maglev-MagLifter R&D Program Concept Mapping Strategic Goals into Technology Objectives

	MagLifter (Space Launch)	Aeronautics (R&D Applications)	Maglev (Ground Transport)	Secondary Opportunities
High- Leverage R&D Opportunities	Laboratory-Level Proof-of-Concept Low Mass Superconductors High Tc Superconductors High-Efficiency EM Propulsion	Laboratory-Level Proof-of-Concept Low Mass Superconductors High Tc Superconductors High-Efficiency Prop.	Laboratory-Level Proof-of-Concept Low Mass Superconductors High Tc Superconductors High-Efficiency Prop.	Laboratory-Level Proof-of-Concept Low Mass Superconductors High Tc Superconductors (Mfg, Components)
Core Technologies and Capabilities	Testbed Demonstrations Very High- Acceleration EM Propulsion Low-Cost Guideway Light-Weight Vehicles	Testbed Demonstrations High-Acceleration EM Propulsion Low-Cost Guideway Light-Weight Vehicles	Testbed Demonstrations High-Acceleration EM Propulsion Low-Cost Guideway Light-Weight Vehicles	Testbed Demonstrations Magnetic Bearings SMES Precision Tunnel Systems CMGs
Technology and Systems Validation	System-Level Demonstration Mark I Demo Mark II Demo (R&D for Mark III development)	System-Level Demonstration Hypersonic Test Track Experiments Sub-Scale Launch Demo (Mark II scale)	System-Level Demonstration Relevant System- Level Demos (Mark I, Mark II)	n/a

MSBS Applications

Support Interference-Free Aerodynamic Testing Generic interference evaluation
Transport cruise drag Dynamic stability
High angle-of-attack aerodynamics

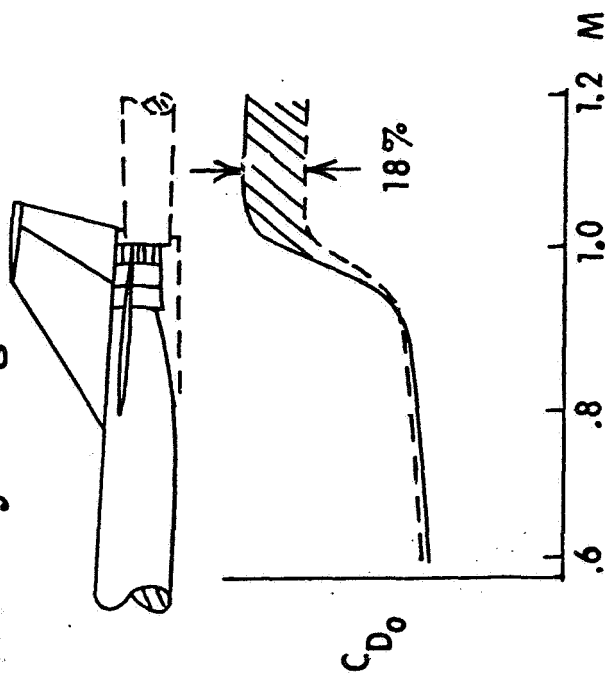
Dynamic Stability Testing
Forced oscillation - unlimited trajectory opportunities
"Modal" oscillations Random excitation - system identification

Unsteady Aerodynamics
Vortex flows / vortex breakdown Dynamic stall
Unsteady separation and wakes

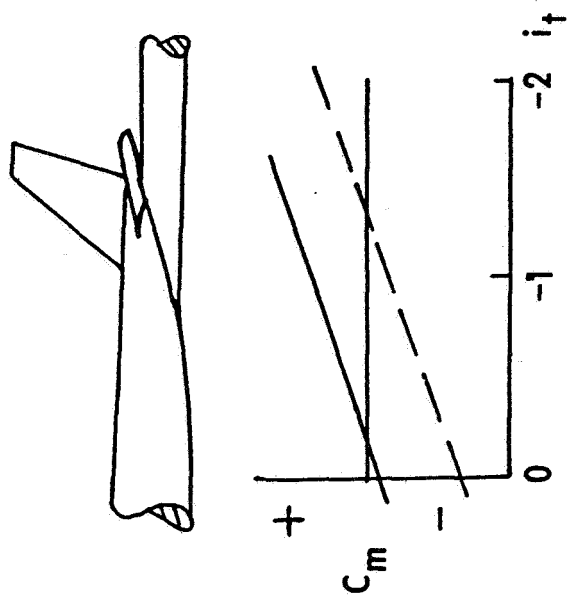
Unconventional Testing
Store separation. Multi-body separation

EXAMPLES OF SOME MODEL SUPPORT PROBLEMS

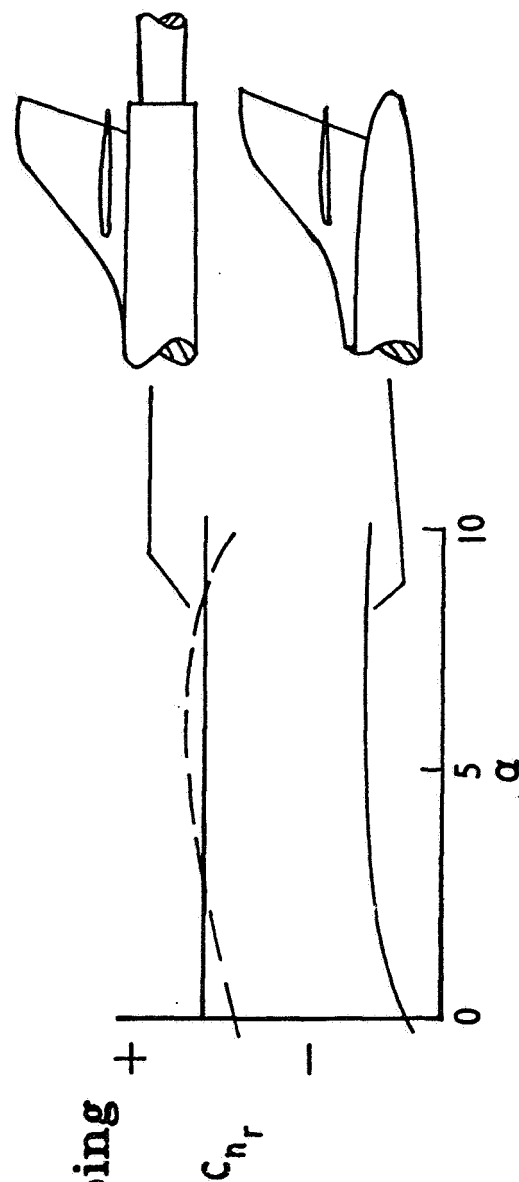
● Afterbody drag



● Trim & tail loads



● Yaw damping



Future Applications

Program Focus

Aerodynamics

Unsteady aerodynamics, dynamic stability, support interference elimination, unconventional testing

Technology development

MSBS is a powerful technology driver

Specific Technologies

Position and attitude sensors; control systems and algorithms; magnetic configurations; electromagnet design and analysis; superconductivity

Key Spin-Off Technology

Powerful, AC-capable, high temperature superconducting electromagnets

TRACK MISSION

- **SIMULATES BY MEANS OF ROCKET SLEDS**
 - Critical portions of flight trajectories
 - Dynamic events
 - Special environmental conditions
- **BRIDGES THE GAP BETWEEN LABORATORY AND FLIGHT**
- **SHIFT RISK OF FAILURE FROM FLIGHT TO GROUND TESTING**

TRACK CHARACTERISTICS

- **Length: almost 10 miles|| Sled velocities at 10,000 ft per sec**
- **Two rails: 50,788 feet**
- **Narrow gage rail: 15,200 feet**
- **Gages: 7 feet and 26.31 inches**
- **Alignment: withing 0.005 inch**
- **Continuously welded**

PROVEN TEST CAPABILITY

AIRCRAFT

- Crew Escape
- Airblast
- Birdstrike
- Aeropropulsion
- Munitions Launch
- IRCM

MISSILES

- Guidance
- Aerodynamics
- Aeroelastics
- Dispenser
- Seekers
- Components

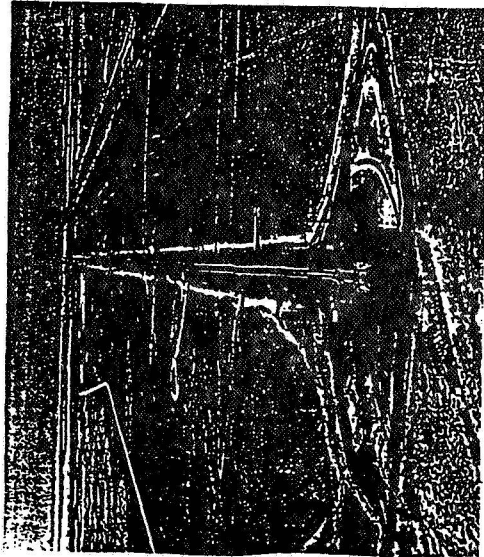
ENVIRONMENT

- Rain / Ice
- Aerothermal
- Dust
- High G
- Hypersonic

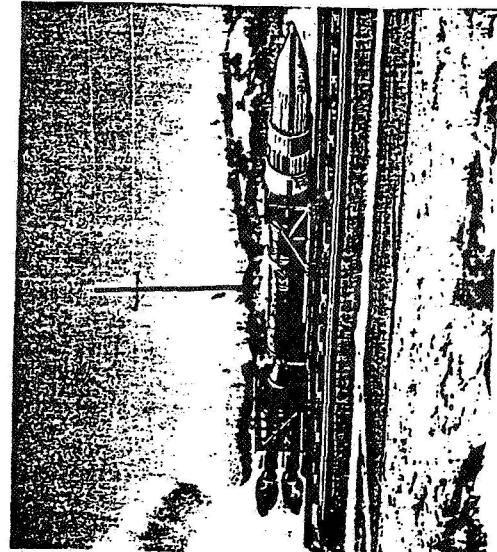
OTHER

- Warhead / Fuse
- Impact
- Decelerators
- Survivability
- Vulnerability
- Lethality
- Live Fire

HOLLOMAN HIGH SPEED TEST TRACK



"ON TRACK FOR TOMORROW"



TRACK MISSION

- SIMULATES BY MEANS OF ROCKET SLEDS
 - Critical portions of flight trajectories
 - Dynamic events
 - Special environmental conditions
- BRIDGES THE GAP BETWEEN LABORATORY AND FLIGHT
- SHIFT RISK OF FAILURE FROM FLIGHT TO GROUND TESTING

TRACK CHARACTERISTICS

- Length: almost 10 miles
- Two rails: 50,788 feet
- Narrow gage rail: 15,200 feet
- Gages: 7 feet and 26.31 inches
- Alignment: within 0.005 inch
- Continuously welded

TEST VELOCITIES: Sled velocities approaching 10,000 feet per second

ADVANTAGES OF TRACK TESTING

- Full-Scale Testing
- Realistic Simulations
- Accurate/Timely Results
- Cost-Effective Approach
- Flight-Test Environment
- Test Item Recovery
- Testing of Prototypes
- Early Development Risk Reduction

HOLLOMAN TEST TRACK - WHY MAGLEV?

- **CURRENT CAPABILITY:**
 - 1.5 - 2.4 KM/SEC
 - VIBRATIONS MAY EXCEED FLIGHT ENVIRONMENT
- **LIMITATIONS**
 - RAIL INDUCED LOADS/IMPACTS
 - PROPULSION
 - SLIPPERS
 - ----- “and with MAGLEV capability”
- **ELIMINATES RAIL IMPACT INDUCED LOADS/
VIBRATION**
 - PAYLOADS CAN BE MORE REALISTIC
 - REDUCED SLED STRUCTURE
 - HIGHER VELOCITIES: 3.5 KM/SEC +
- **ELIMINATES SLIPPER WEAR**

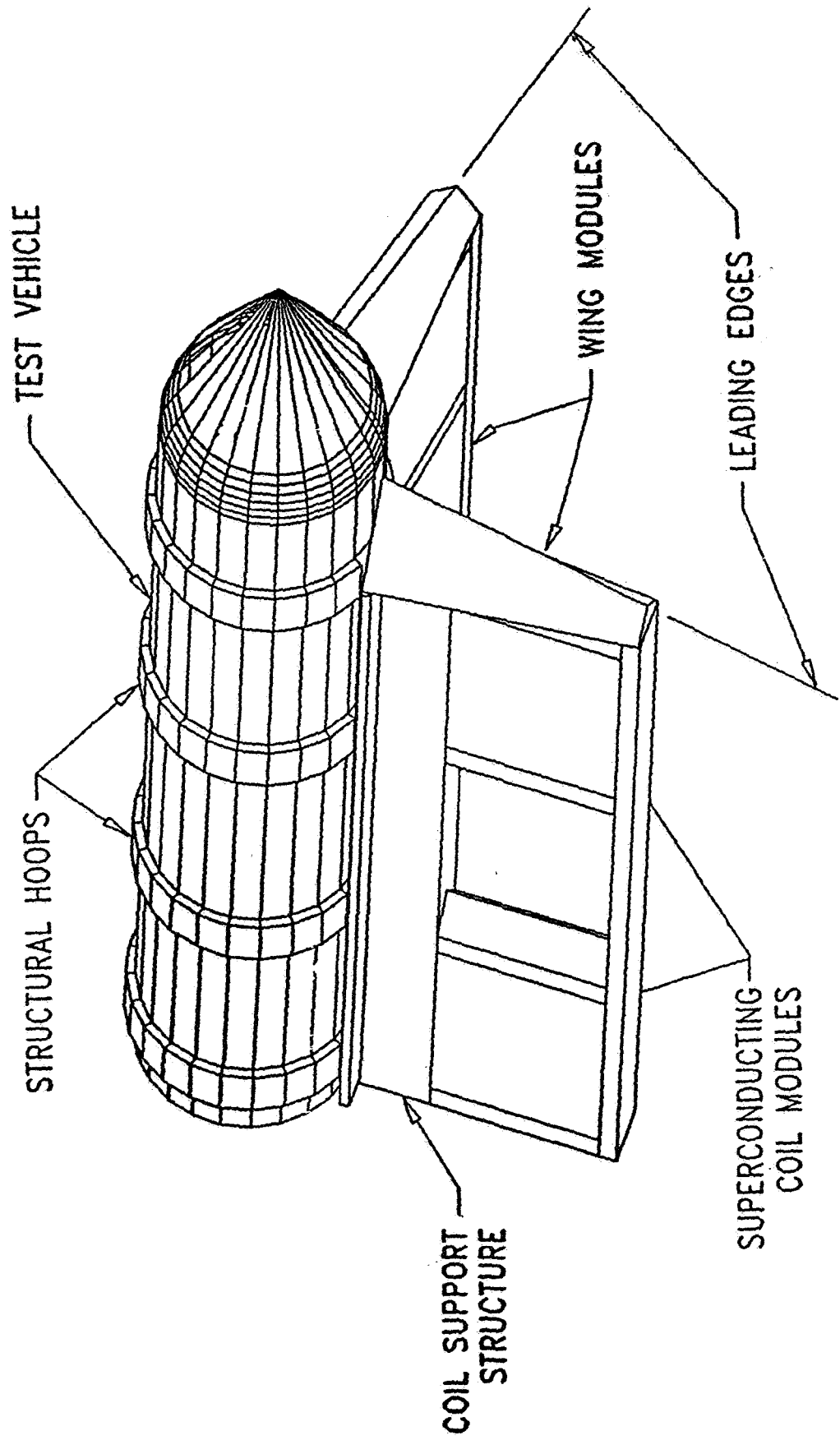
HOLLOMAN AFB MAGLEV TRACK UPGRADES

- Option 1:** **Extend existing track 7 km**
speed capability 2.5 km/sec → 2.7 km/sec
Vibration Levels Unchanged
- Option 2:** **Extend existing track 7 km**
use MAGLEV on extension
speed 2.5 km/sec → 3.5 km/sec
Much Reduced Vibration
- Option 3:** **Extend existing track 9 km**
use MAGLEV on extension
speed 2.5 km/sec → 3.7 km/sec
Much Reduced Vibration

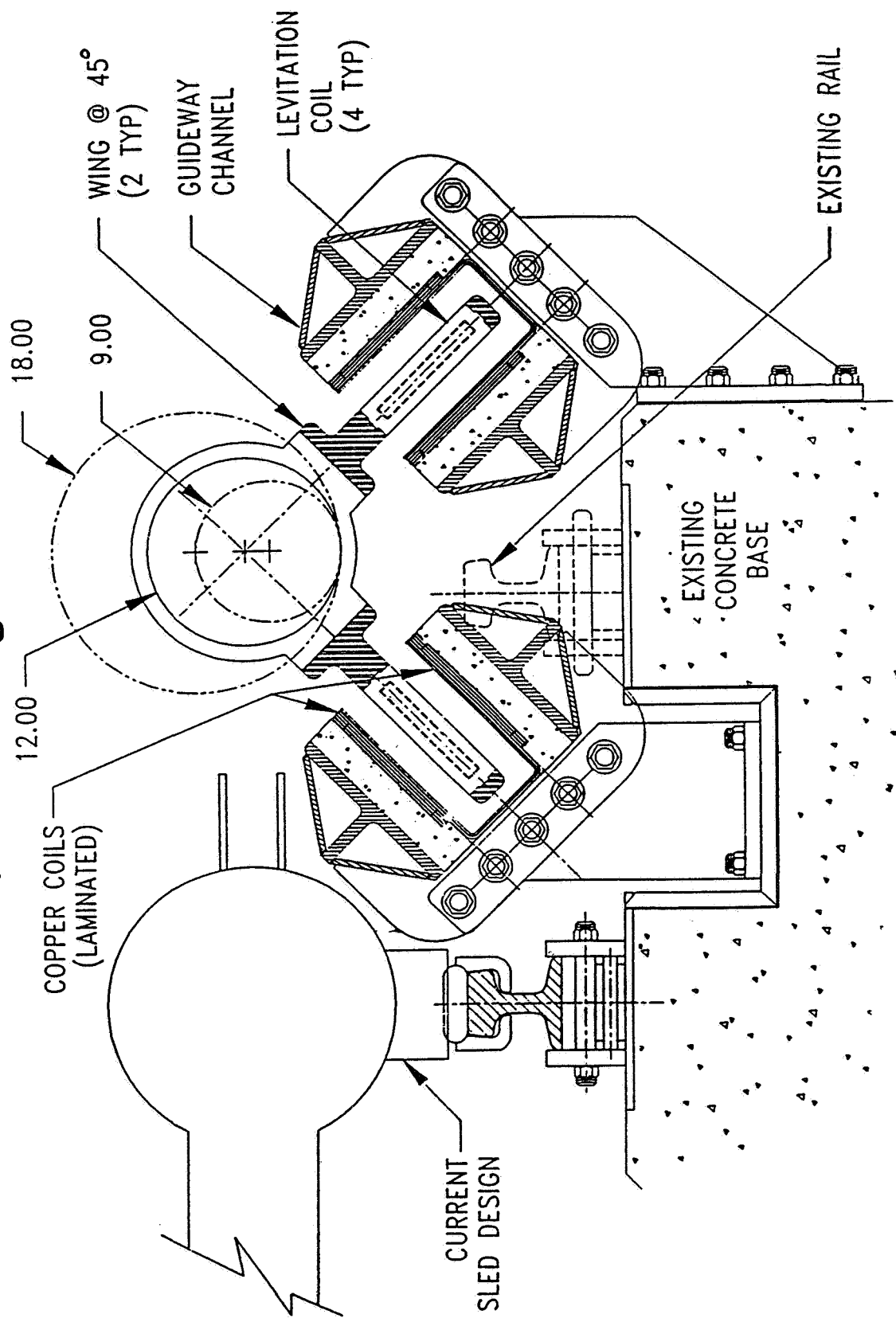
POTENTIAL HYPERVELOCITY MAGLEV APPLICATIONS

- **HYPERVELOCITY IMPACT STUDIES (3 - 4 KM/SEC)**
 - Lethality Tests
- **FIRST-STAGE BOOST OF ORBITAL AND SUB-ORBITAL PAYLOADS**
 - Environmentally compatible launch systems
- **FLIGHT TESTS/WIND TUNNEL TESTS AT HYPERVELOCITY**
 - Piggy - back experiments (free-flight cone-cylinders)
 - Tests of models at full-scale
 - Boundary Layer Transition (no tunnel noise, M8)
 - Materials/Actively Cooled structures
- **HIGH AERODYNAMIC EFFICIENCY PROJECTILES USING AIR-BREATHING ENGINES** - storable hydrocarbon fuel scramjet testing to Mach 11 + in non-vitiated air and $q > 10,000$ (T/W = 100/200)

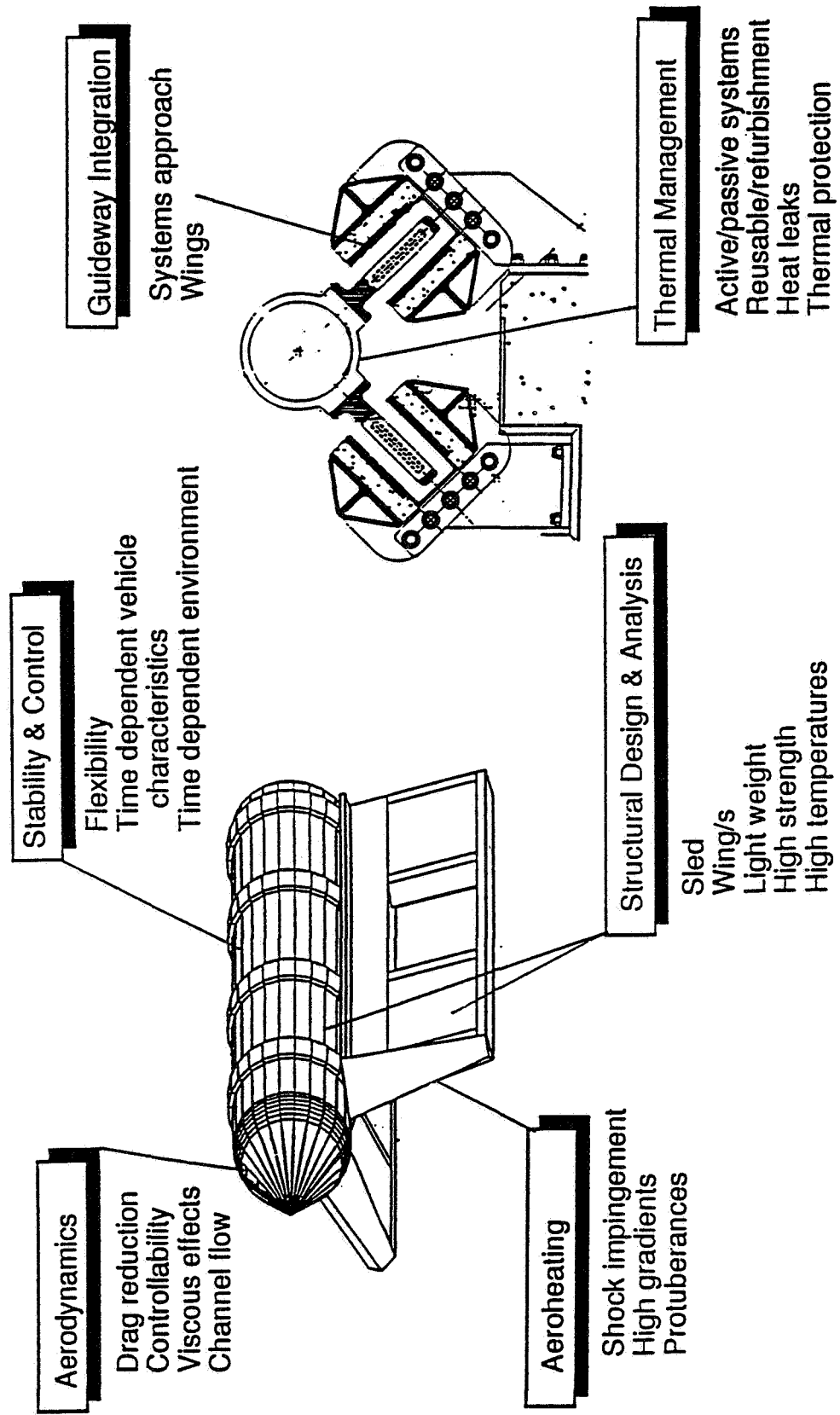
LEVITATED TEST SLED ASSEMBLY



LEVITATED ROCKET SLED RAILS (Double Wing at 45°)

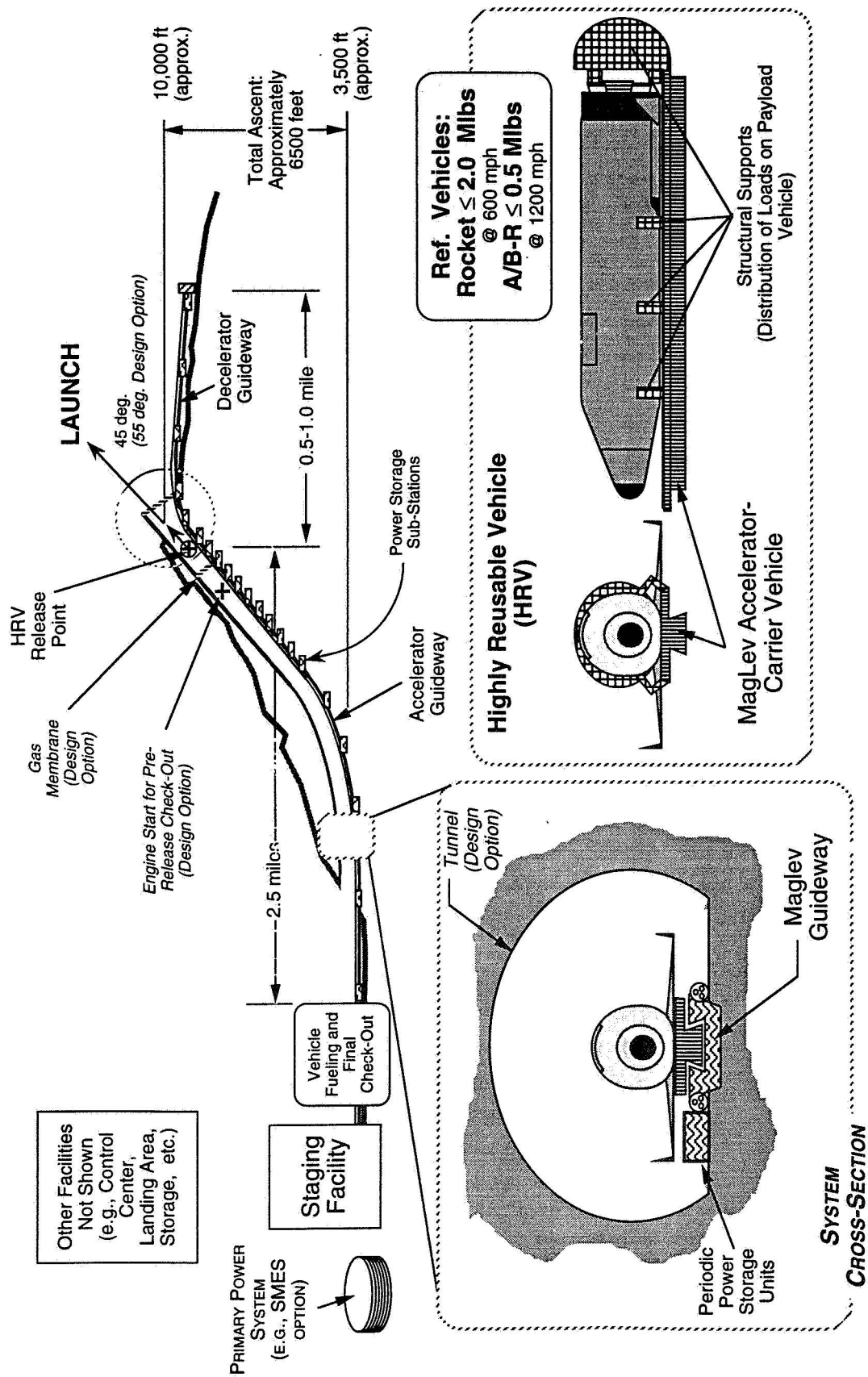


MAGLEV HIGH-SPEED ROCKET SLED DESIGN ISSUES

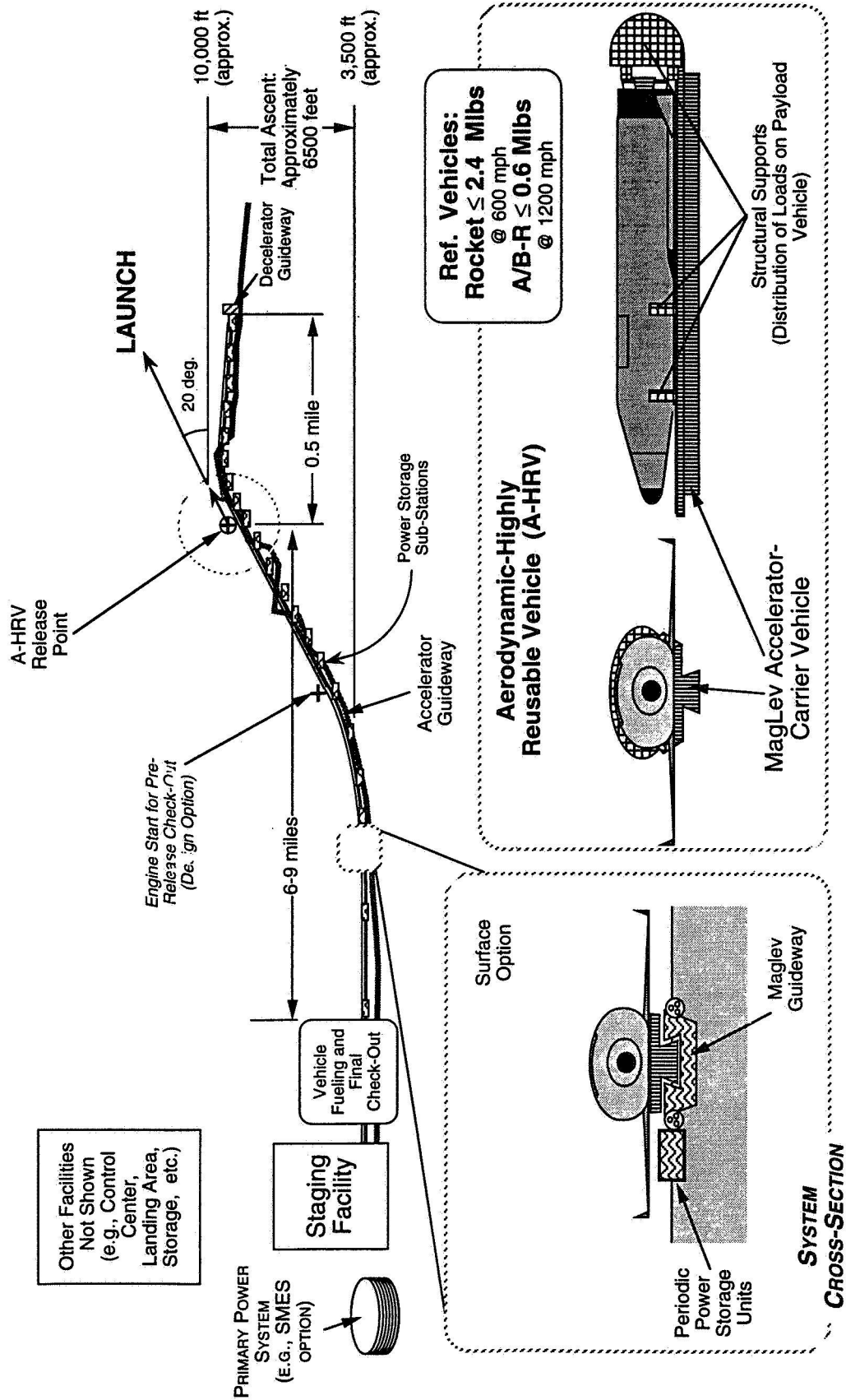


PICTURE of MAGLIFTER CONCEPT

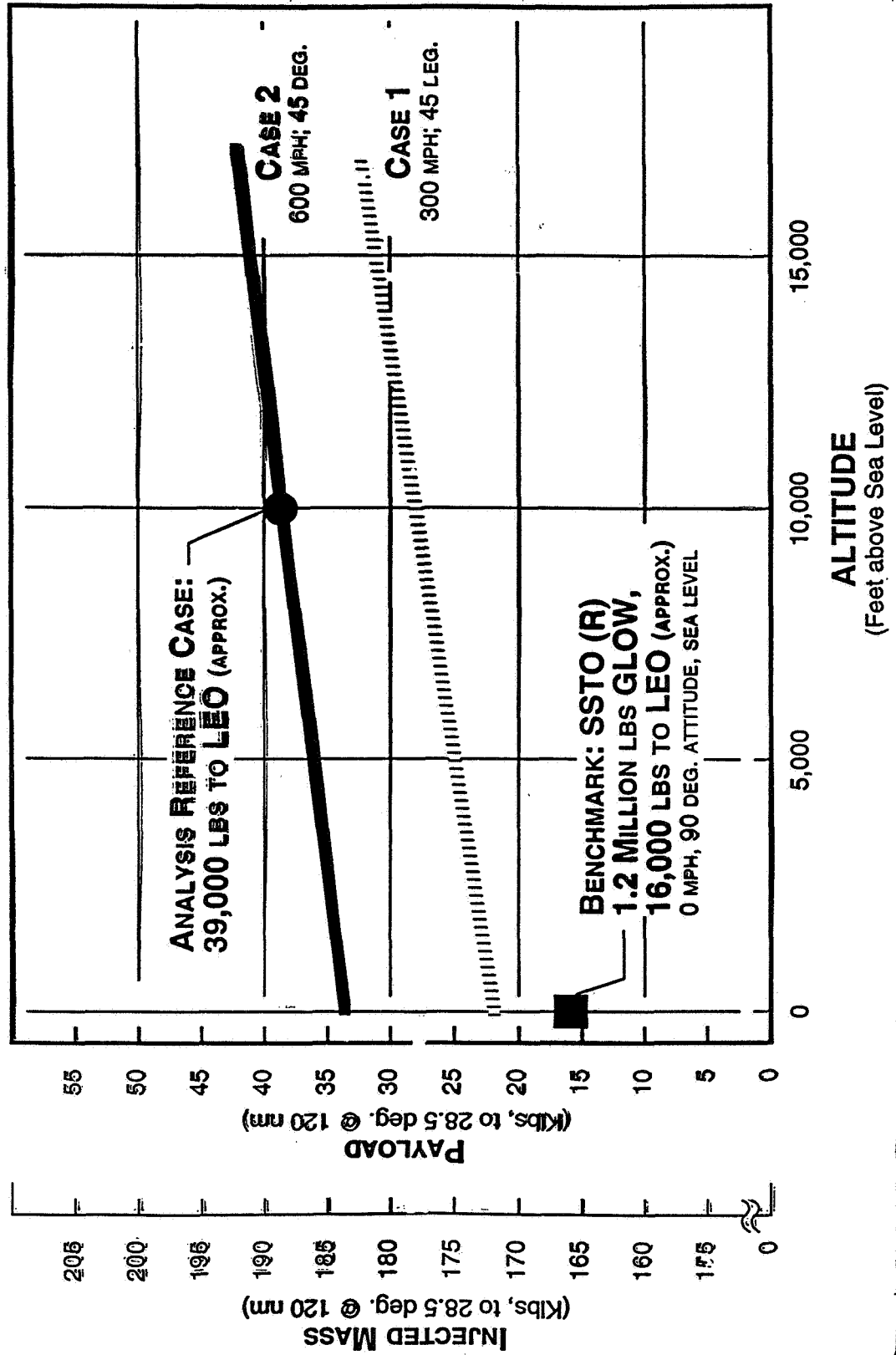
MagLifter — non-Aerodynamic HRV Configuration A "Mark III" Full-Scale System



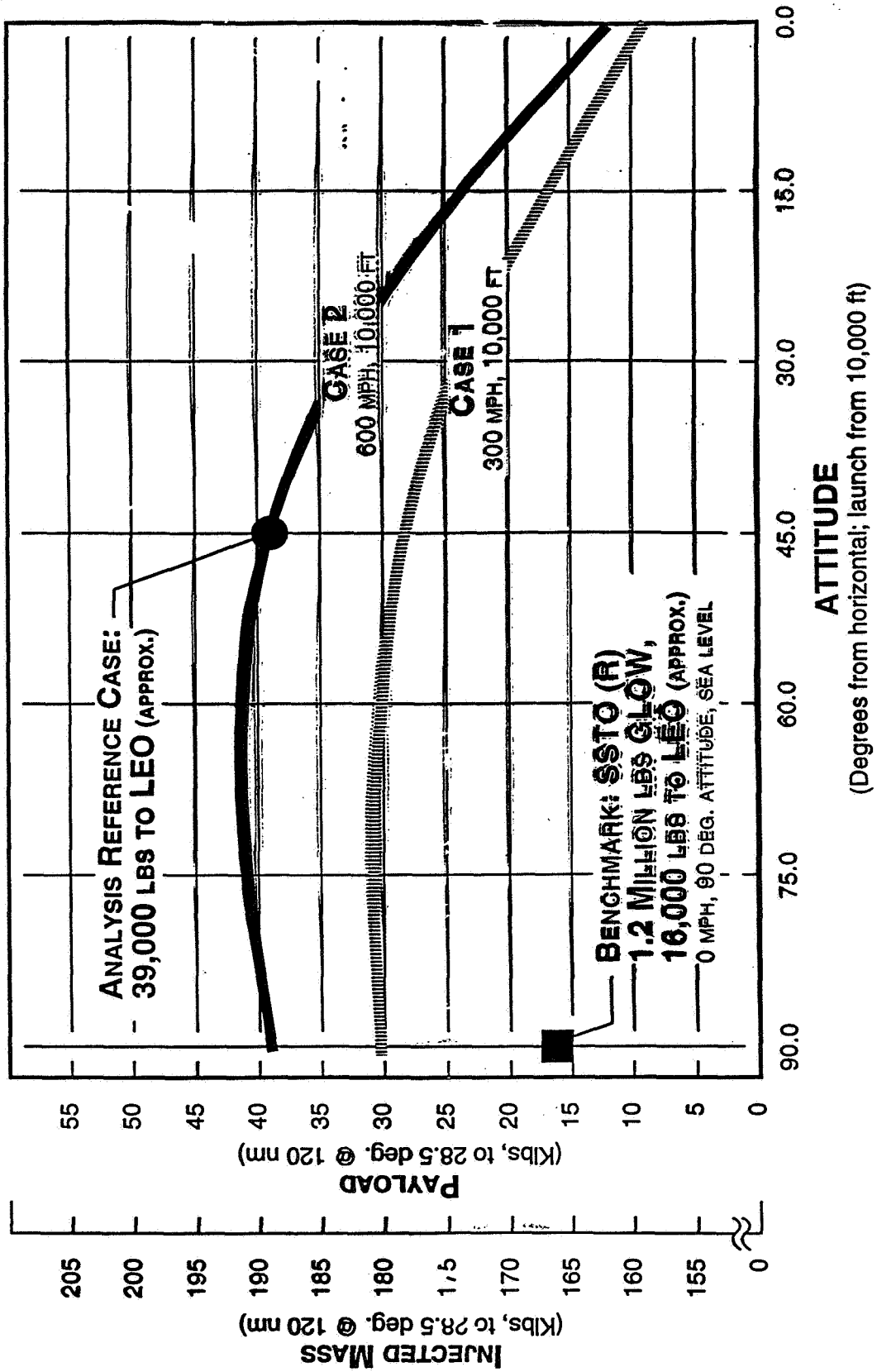
MagLifter — Aerodynamic HRV **Configuration B "Mark III" Full-Scale System**



MagLifter – Payload Sensitivity Analysis (Sensitivity to Altitude and Velocity)



MagLifter: Payload Sensitivity Analysis (Sensitivity to Attitude and Velocity)



MASS TRANSPORTATION MAGLEV

RECENT DEVELOPMENTS IN JAPAN

Selected Maglev Technology Issues

- The following are some of the key technology-related issues facing maglev applications for ground transportation
 - Aerodynamics (ie., reducing drag at high speeds; entering/exiting tunnels)
 - Communications with the vehicle; control of the vehicle
 - Magnet design, cryogenics, helium management
 - High speed switching; speed, acceleration and braking
 - Primary and secondary suspension
 - On-board power; system power supply (interface with utility, substations)
- Other key design and development issues include:
 - System development and implementation cost (guideway, vehicles)
 - Magnetic field levels in the vehicle (passenger safety)
 - Passenger ride quality (transient g-forces inside the vehicle)
 - Route selection and system operations
 - ‘Operations and maintenance’ of the system (logistics, cost, emergencies)
 - Noise (inside the vehicle, outside the vehicle)

Major R&D task: make construction costs competitive with that of the conventional wheel - rail system.

“FAR TERM VISIONS”

--not really, actually mid-to-longer term possibilities which are “different,” require/offer new design paradigms and revolutionary performance improvements

“THE FRONTIERS OF THE RESPONSIBLY IMAGINABLE”

**Dennis M. Bushnell
Senior (Chief) Scientist
NASA-Langley Research Center**

510-01
39475

ELEMENTS OF THE LONGER TERM PROBLEMS IN CIVIL AVIATION

- | | |
|---|--|
| <ul style="list-style-type: none"> • Economics/economic warfare | <ul style="list-style-type: none"> • Aircraft cost/
efficiency/
productivity • Airport/runway
productivity |
|---|--|
-
- **Enhanced demand**

including additional constraints/consideration of

- **Energy conservation**
- **Emissions**
- **Noise**
- **Safety**

STATUS OF U.S. CIVILIAN AVIATION INDUSTRY

CURRENT

- Largest single source of positive trade balance (0[\$20 to 40B/yr])

TRENDS

- Loss of 0 (30+%) market share within last approximately 5 years to airbus industry
- Largest single aerospace and airline systems (Russian/ Aeroflot) becoming players in western civilian aeronautics
- Airbus very aggressive re: technology; e.g.,
 - Composite materials
 - Side stick controller
 - Glass cockpit
 - Excellent wing/hi lift performance

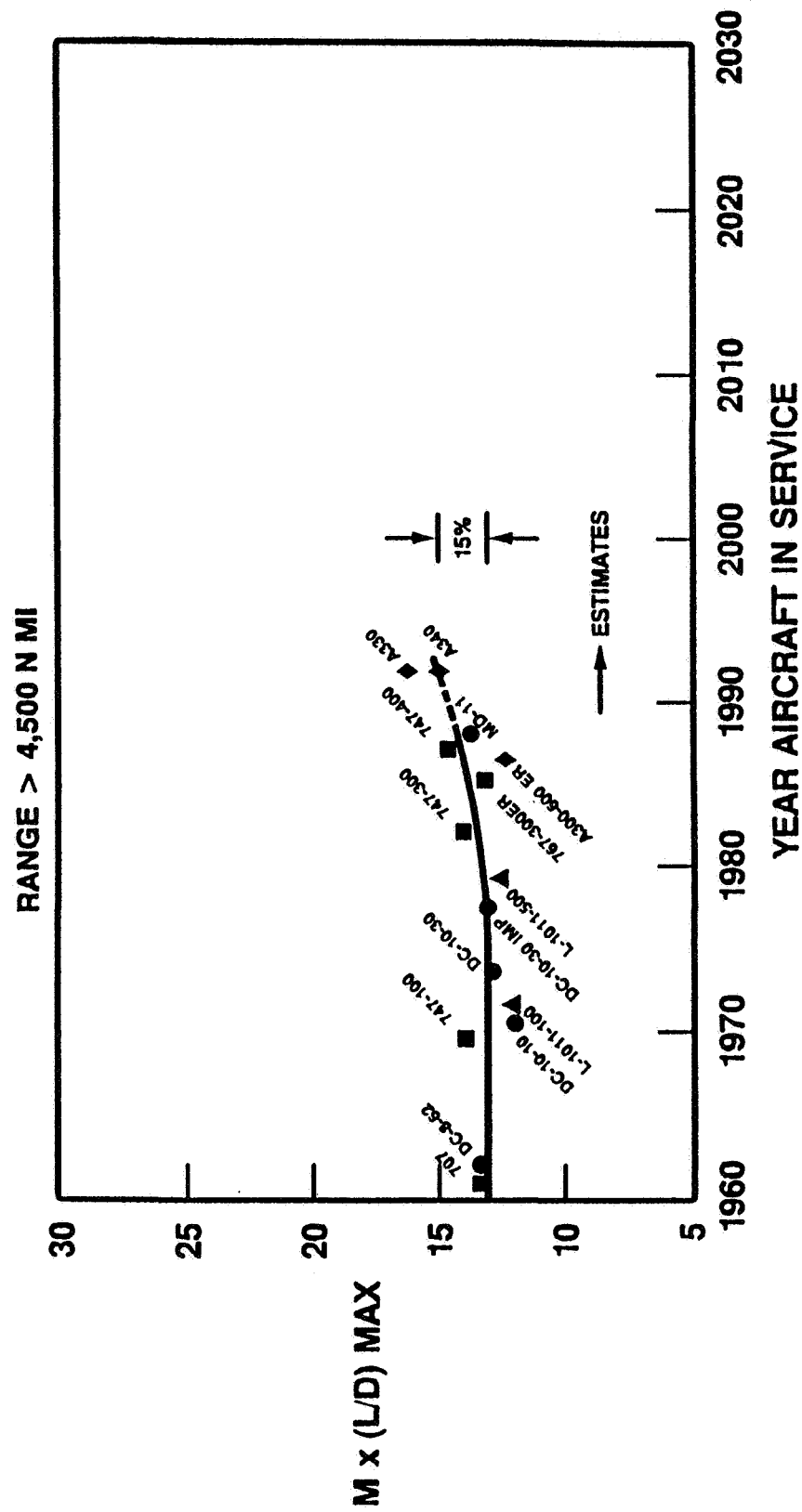
REALITY -- CIVILIAN AERONAUTICS

- Nominally a “mature”/“plateau” industry (for/with “current technology”) increasingly competitive (Airbus, Asians, developing countries, etc.) both economically and technologically
- Difficult for America to compete on cost basis (labor rate issue)
- “Desperately seeking something” (NASA X-plane program)
 - Need to “surface”/create/work new/different technologies which can establish a new/higher “plateau”
 - GA
 - VTOL
 - CTOL
 - HSCT

FOR SUCCESS IN ECONOMIC WARFARE

Americans cannot work more cheaply than others (e.g., the Chinese), nor more dilligently than others (e.g., the Japanese), therefore, we must work more intelligently

**Brandin/Harrison
“The Technology War”**



AERODYNAMIC EFFICIENCY EVOLUTION OF LONG-RANGE TRANSPORT AIRPLANES

SUGGESTED AERO “HORIZON” MISSIONS

PART 1--TRANSPORTS

- **Medium (450 pax max) and large (>600 pax) [different solution space in each size range]**
- **True “all-weather” flight capability**
- **Double L/D**
- **Half EW**
- **10 db noise reduction**
- **Double $C_{L, \text{MAX}}$**
- **1/2 number of parts**
- **1/2 vortex hazard/spacing**
- **50 percent reduction in initial/fuel/maintenance costs**
- **75 percent reduction in emissions**

- **A major design constraint for CTOL aircraft is L/D at takeoff**
 - **At takeoff, 90 percent of total drag is drag-due-to-lift**

From Paul Rubbert (Boeing)

TECHNIQUES FOR INDUCED DRAG REDUCTION

• Increased wing aspect ratio	Planar vortex sheet
• Elliptical span loading	
• Spanwise/streamwise curvature	Non-planar vortex sheet
• Sheared wing tips	
• Serrated wing trailing edge	Energy/thrust extraction from tip vortex
• Wing tip turbines	
• Winglets	
• Vortex diffuser vanes	
• Wingtip sails	Alteration of wing tip boundary condition
• Wing tip engines	
• Porous wing tips	
• Wing tip blowing	
• Rotating cylinder at tip	"Elimination" of wing tips
• Ring wing	
• Joined wings/tails	Propulsion integration
• Aft-mounted engines	
• Over-wing blowing	

CTOL ADVANCED CONFIGURATION AERODYNAMICS

NEW WRINKLES ON OLD IDEAS, OR: IDEAS REEXAMINED IN TERMS OF TECHNOLOGY ADVANCES AND SYNERGISMS

- **Strut braced wings**
- **Double fuselage**
- **Bi-plane**

DRAG ADVANTAGES OF STRUT- BRACED WING

- Thinner wing sections
 - Higher drag-rise Mach number
 - Lower pressure drag
 - Higher aspect ratio
 - Lower induced drag
 - Allows tip engines for DDL reduction
 - Enhanced laminar flow/LFC
- reduced wing sweep

“UPDATES” TO STRUT-BRACED WING CONCEPT

- Span reduced to FAA standard “80M box” for gate compatibility
- Wing tip engines for drag-due-to-lift and vortex hazard reduction
- Third engine in tail with thrust vectoring for engine out

Preserve/Keep:

- Strut-bracing utilized for reduced for wing thickness and sweep, greatly enhancing laminar flow

OPPORTUNITIES/APPROACHES SYNERGISTICALLY INTEGRATED PROPULSION AND AIRFRAME (open thermodynamic system)

<i>Approach</i>	<i>Benefit</i>
• Wing tip engine	-- 40%+ DDL red. (cruise) -- Wake vortex hazard red.
• Circulation control wings	-- Factor of 4+ increase in C_L -- Reduced cost -- Improved control/maneuverability
• Goldschmeid wing (suction for pressure recovery, inj. near TE)	-- Up to 50% wing drag cancellation via static pressure thrust
• Boundary Layer Inlet	-- Order of 10% to 20% increase in propulsion efficiency
• Thrust Vectoring	-- Control
• HLFC Suction as Hi-lift L.E. Device	-- Increased lift, red. cost
• Wing Tip Injection	-- Red. DDL/ incr. L/D, red. vortex hazard
• Ejector wing	-- Improved str./aero efficiency

'UPDATES" TO DOUBLE FUSELAGE CONCEPT

- **Advanced roll control**
- **Delete outer wing panels**
- **"Midwing" site of:**
 - **Landing gear**
 - **Engines (including B.L. injection)**
 - **Pilot cabin**
- **Drag-due-to-lift and vortex hazard reduction**
 - **Fuselage/wing intersection/interaction tailoring**
 - **Empanage tailored to extract thrust from residual wing-induced fuselage vorticity**
- **Detachable/changeable fuselages to greatly improve duty cycle/ROI**

BI-PLANE STATUS

(See paper by M. K. Zyskowski, N95-26956)

NOTE: *Ring-wing should also be re-examined*

- 25% cruise CD reduction compared to “equivalent” monoplane (primarily drag-due-to-lift reduction)
- 31% increase in L/D max
- Significant additional drag reduction available via laminar flow control (reduced chord length, mitigates increased wing wetted area)
- Has improved pitching moment characteristics vis-a-vis monoplane
- Inately lower span, also reduced vortex hazard
- Up to 60% reduction in wing weight

} experimental results

IMPLICATIONS OF DRAG REDUCTION UPON HSCT PERFORMANCE

- Fuel = 62% of gross takeoff weight including (8% reserves)
- Payload = 8% of gross takeoff weight
- 1% drag reduction corresponds to order of --
 - 3,500 lb. empty weight reduction
 - 16,000 lb. takeoff weight reduction
 - 16 passenger payload increase
 - Reduces fuel weight equivalent to 1/2 of payload
- LFC over 1/2 of wing

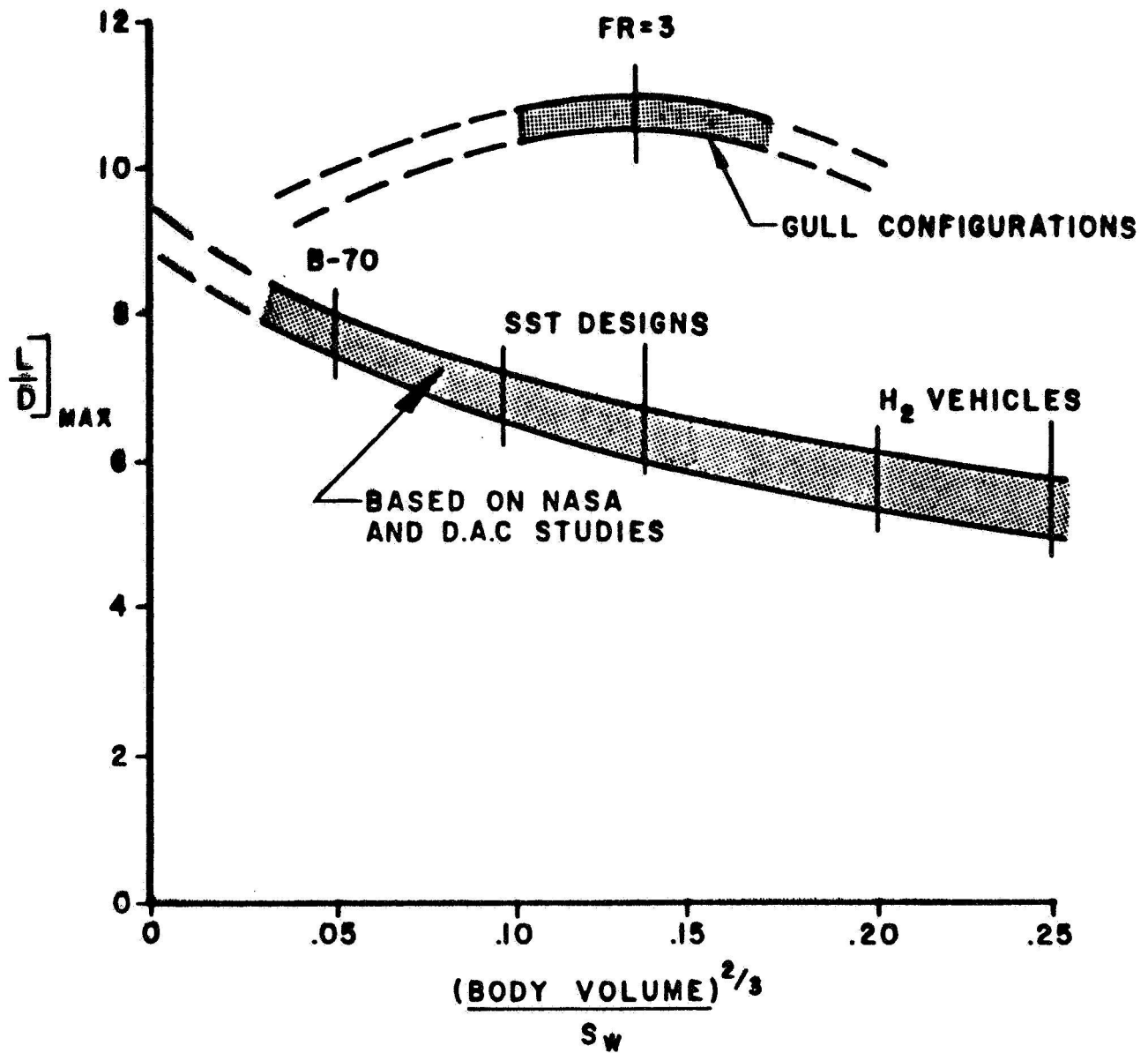
SUPERSONIC DRAG REDUCTION

HOW LOW CAN YOU GO?

- **Friction drag -- could be reduced 50-80% via laminar flow control**
- **Volume wave drag -- could be nearly eliminated by favorable shock wave interference**
- **Drag-due-to-lift -- arrow or yawed wing would minimize this drag component**

EFFECT OF BODY VOLUME ON LIFT-DRAG RATIO

$M = 3.0$
 $Re \approx 10^8$ (TURBULENT)



BENEFITS/ISSUES--SUPERSONIC

MULTI-BODY/FAVORABLE

INTERFERENCE

BENEFITS

- Favorable interference wave drag reduction
- Reduced body Reynolds Number, enhanced laminar flow
- Thinner sections, reduced wave drag
- Improved structural efficiency

Multi-body

ISSUES

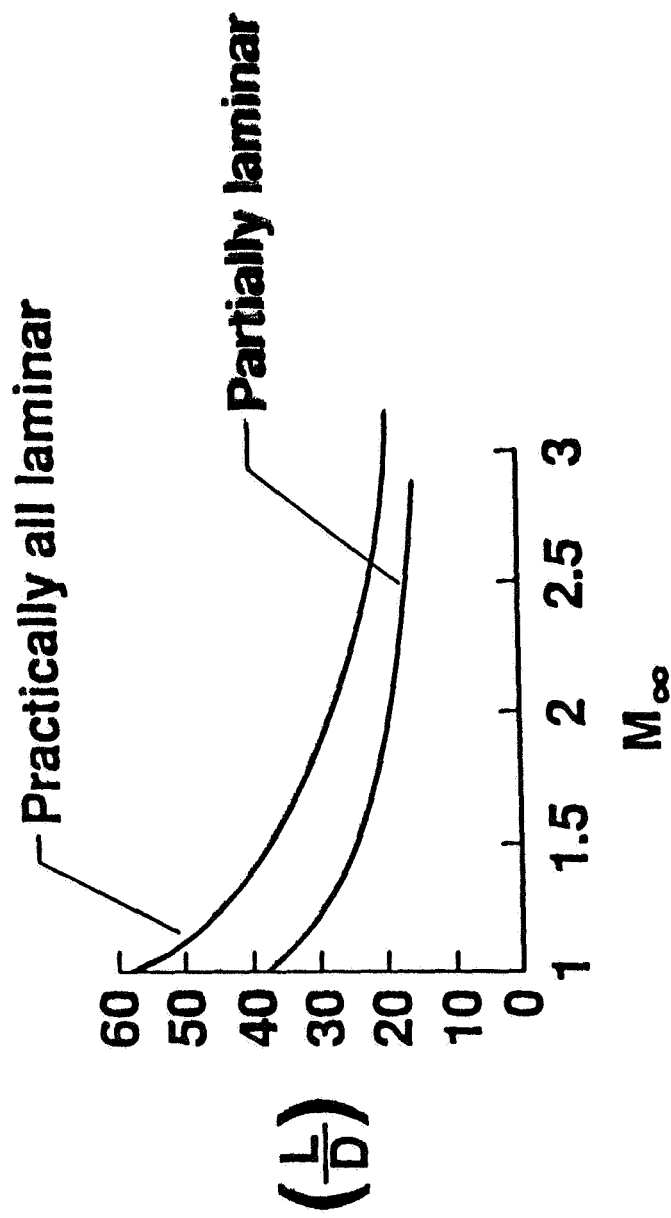
- “OFF design” (variable geometry/injection)
- Separation control for shock interaction regions
- Influence(s) upon sonic boom

FEATURES/ADVANTAGES

Pfenninger Strut-Braced Extreme Arrow HSCT Configuration

- **Minimum wave-drag-due-to-lift via extreme arrow planform (enabled by strut bracing)**
 - **Also increases aspect ratio/reduces vortex DDL**
- **Mid-wing fuel canisters utilized for favorable volume-induced wave interference and load alleviation**
- **Low wing Reynolds number favorable to extensive laminar flow**
- **“Natural” laminar flow on fuselage and mid-wing canisters**

SST WITH LFC AND HIGHLY SWEEPED HIGH ASPECT RATIO STRUT-BRACED WING AND MULTIPLE BODIES



SUPERSONIC NATURAL LAMINAR FLOW

APPLICATIONS/CONFIGURATIONS

- **FUSELAGE** -- bluntness, heat strips, synthetic vision,
aft wing/door placement
- **WINGS** -- (supersonic leading ledges, reduced x-flow)
 - Outboard sections, reduced wing/gross weight, improved
low speed performance/lower drag
 - "Reverse" delta wing, improved low speed performance/
lower drag

OPTIONS FOR MULTISTAGE AIRCRAFT

- **Separate subsonic takeoff and landing carrier A/C (e.g., 747, Roskam)**
- **Flyback integrated stage to accommodate the fuel weight/noise/high lift/heavy gear conditions unique to takeoff**
- **In-flight refueling**
- **Takeoff assistance**
 - **Ski jumps on takeoff runways**
 - **Ground trolleys**
 - **Etc. (laser-guided water jets)**

SUMMARY

SAMPLE POSSIBILITIES FOR REVOLUTIONAL AERODYNAMIC PERFORMANCE IMPROVEMENTS

Subsonic/CTOL Transports

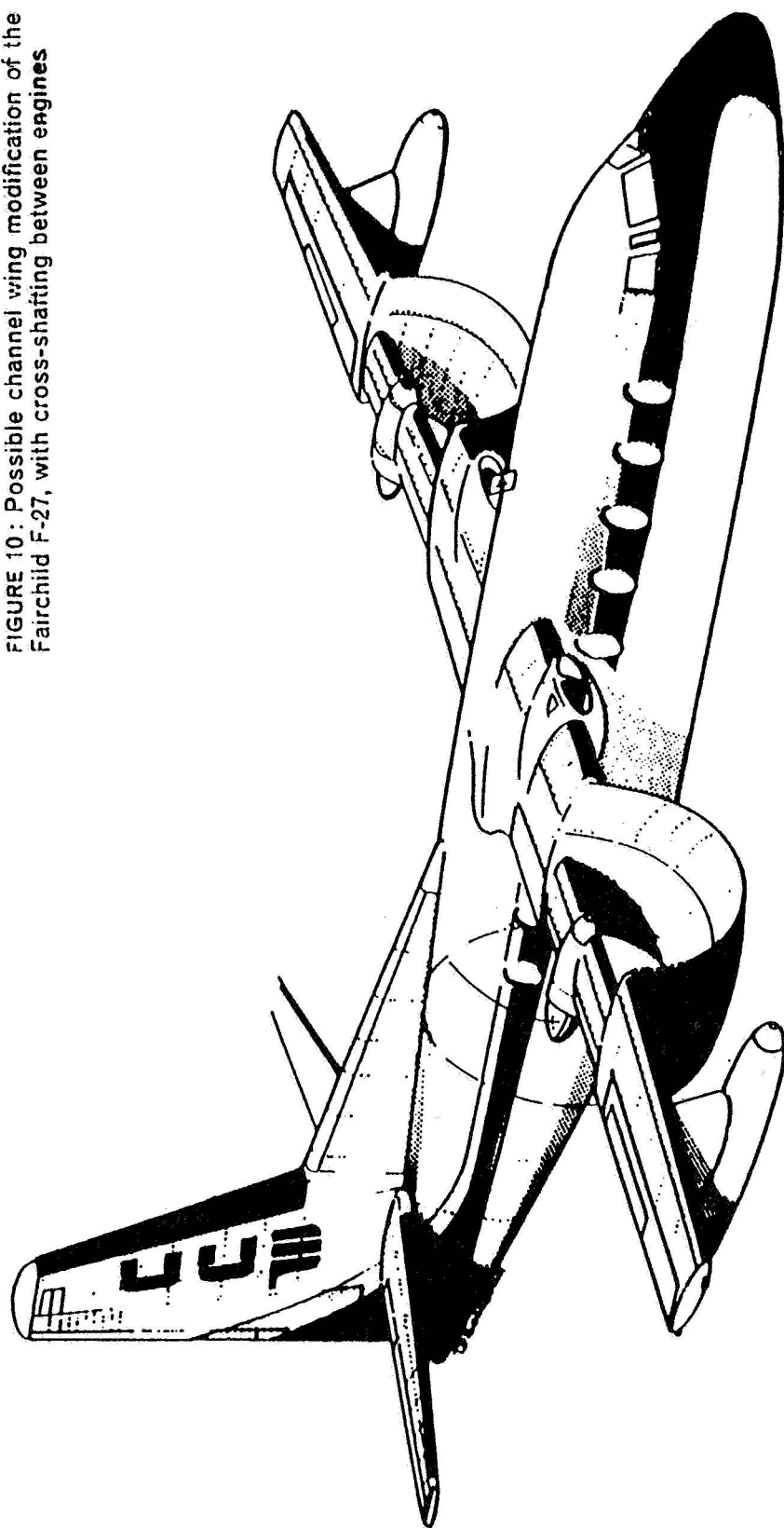
- End-point “conventional” design
 - Extensive laminar flow
 - Large aspect ratio or tip engines (via strut bracing) for DDL reduction
- Double fuselage mid-wing, ring wing/biplane
- Synergistic combinations (spanloaders)

– Load-carrying	
– Lifting surfaces	
– Propulsion	plus laminar flow control

Supersonic/HSCT Transports

- Spanloader oblique wing ($M \approx 1.6$)
- Favorable wave interference
- Extreme arrow wing via strut bracing/load alleviation

FIGURE 10: Possible channel wing modification of the Fairchild F-27, with cross-shafting between engines



**PROSPECTIVE CHANNEL WING
V/STOL PERFORMANCE
IMPROVEMENT OPPORTUNITIES
*(Combination of Powered Lift and
Power-Induced Aerodynamic Lift)***

- Circulation control (increase lbs. of lift/H.P.)
- Separation control (improve channel performance)
- Laminar flow control (for cruise performance)
- Strut-bracing (decreased DDL, weight)

OPPORTUNITIES SUMMARY

ADVANCED CONCEPT PROPULSION

<u>APPROACH</u>	<u>APPLICATION</u>
• Ceramic wankel (Mollar)	• VTOL converticar, GA, RPV
• Pulse detonation wave cycle	• Rocket, air-breathing (space access, HSCT, CTOL)
• Lithium-air engines (fuel cells)	• HALE (ersatz satellite capability), VTOL, GA
• Advanced hypersonic cycles (pre-mixed/shock enhanced combustion, liquid air cycles with advanced separation technology, RBCC endothermic hydrocarbon fuels)	• Space access, cruise
• Endothermic fuel-cooled gas turbine engines	• CTOL, HSCT

ADVANCED CONFIGURATION RESEARCH MATRIX

Discipline Elements (and their interactions)	<u>Figures of Merit</u>	<u>Configuration Possibilities</u>	<u>Sample Technologies</u>
• Systems	• Costs	<u>CTOL</u>	• Fuel cooling
• Aerodynamics	-Development -Life cycle	• Double fuselage/mid wing	• Brilliant structures
• Acoustics	• Aero efficiency	• Strut-braced A/C	• LFC/HLFC
• Propulsion	-L/D, Hi-lift	• Blended-wing bodies/ spanloaders	• Circul. control
• Structures	• Emissions	• Ring wing/biplane	• Flow separation control
• Materials	(Ozone, Greenhouse)	<u>HST</u>	(incl. cruise)
• Controls/ Electronics	• Propulsion efficiency	• Oblique wings	• DDL red.
• Human Factors	• Structural efficiency	• Supersonic leading edges/ HLFC	• Strut bracing
	• Airport productivity	• Favorable wave interference	• Electronics/MEMS
	-Acoustics	• Strut-braced extreme arrow wing	• Vortex control
	-“All weather”	• Multi-stage A/C	• Free mixing control
	-Hi-lift	-Fly-back	• Turbulent drag red.
	• Safety	-Takeoff assist	• Thrust vectoring
			• Variable geometry
			• Propulsive-aero favorable interaction
			• PDW engines

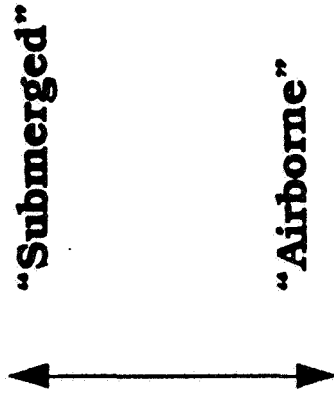
(CONVENTIONAL) AIRCRAFT VERSUS SHIP FOR “STRATEGIC MOBILITY”

Aircraft has:

- **10X speed**
- **1/100 cargo capacity**
- **Approximately same construction cost
0(\$200M+)**

CIRCUMVENTION APPROACHES FOR (DISPLACEMENT HULL) SURFACE WAVE DRAG

- Submarine
- Swath Ship
- Planing Hull
- Hydrofoils
- Surface Effect Aircraft



“100+ KNOT SHIP”

(Prospective Features)

- **“Swath-Like”**
 - Surface-piercing struts allow favorable interference for wave drag reduction
 - Contour upper works for aero drag reduction
 - (Residual) drag problem on buoyancy hulls
- **Drag Reduction on “Swath” Buoyancy Hulls**
 - Goldschmied/pressure-thrust stern(s)
 - Skin friction drag reduction via one or more of the following
 - On-board cultured polymer (feedstock = phytoplankton filtered from cooling water)
 - Surface boiling
 - Supercavitation
 - E-M turb control
 - Downstream translating walls
- Smooth(er) surfaces for roughness drag reduction, (“natural” anti-fouling)
- Nose “swords” (ala Kiev research)

SUGGESTED AERO “HORIZON” MISSIONS

PERSONAL AIRCRAFT

- **Affordable ($\approx 30K+$, in quantity production)**
- **Safe**
- **VTOL**
- **“Converticar”**
- **4 person, ≈ 2000 lbs. EW**
- **FULLY AUTOMATIC (NAV., ATC., OPS.)**
- **Acceptable acoustics/maintenance**
- **“All weather”**
- **Helo or vectored lift-fan**
- **At least 160 kn. cruise**
- **Should significantly reduce capital costs of long distance highways**

ADVANTAGES OF PERSONAL HELICOPTER VIS-A-VIS PRESENT AUTO

- **Faster (200 MPH+ vs. 40 MPH (in traffic) for approximately same size/cost**
- **Fully automatic operation**
 - **Vastly improved safety (operator error major cause of accidents)**
 - **Allows transport of the infirm and inebriated**
- **Allows more even distribution of population over much wider area**
- **Allows more personal (a) “elbow room,” (b) privacy, (c) freedom of choice, and (d) “action radius”**
- **Reduces usage of CTOL airports for short/medium trips**
- **Scheduled arrival times (through automatic operation/ATC)**
- **Allows cost savings due to reduced need for**
 - **Highways**
 - **Bridges**
- **Revolutionizes transport industry (1/5 of GNP), provides excellent escape method for fire in high rise buildings**

EMERGING KEY INGREDIENTS OF AN AFFORDABLE AUTOMATIC SYSTEM

- Civilian utilization of high resolution GPS (inexpensive, accurate)
- Personal satellite commun. systems (inexpensive, real-time global coverage)
- Extensive AAV/UAV/RPV/UTA (primarily military-developed) technology (inexpensive, fault-tolerant controls/communication software/sensors, etc.)

SUMMARY

There are multitudinous “different” concepts available which appear to offer revolutionary improvements in all metrics in the various mission arenas

- Personal aircraft**
- Subsonic long haul**
- HSCT**
- V/STOL**
- These concepts require extensive evaluation and optimization to determine both technical and market reality/feasibility**
- Such research is required to provide a renaissance in/ensure continued viability of U.S. civilian aviation industry**

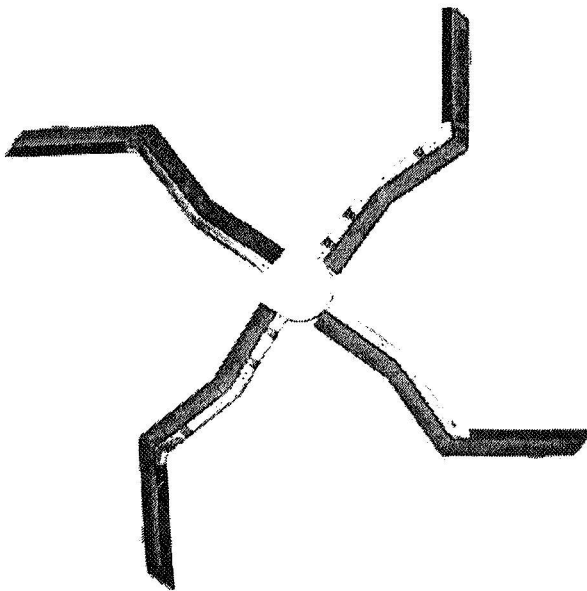
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History, A Projection of the Future: A Rotary Wing Perspective

**Robert J. Huston
Distinguished Research Associate
NASA Langley Research Center**

**Transportation
Beyond 2000
Engineering Design
for the Future**

September 26-28, 1995



Rotorcraft engineering is an area that sometimes doesn't get an awful lot of respect. I can substantiate that by quoting Wilbur Wright. The punch line is:

"... The helicopter is much easier to design than the airplane but is worthless when done."

The quote is from the Dayton Herald (Ohio) and was given to my friend Ralph Alex, then the Sikorsky XR4 project engineer, on the occasion of the delivery of the Army's second helicopter to Wright Field in May 1942. (The first was the De Bothezat machine, delivered in 1922.) Several times over several days, Ralph Alex and Igor Sikorsky offered Orville Wright a ride in the Sikorsky helicopter. Wright had politely refused each offer. Finally, Orville explained that he could not accept because he did not believe the machine was practical and, by way of justification, offered a copy of an article containing the previous quote by his brother Wilbur. It should be noted that the XR-4 helicopter, rolled from the factory on December 7, 1941, was the prototype for 129 helicopters delivered to the U. S. Army by September 7, 1944. An additional 488 helicopters (R-5s and R-6s) were built before the end of WW II. (References are given for additional reading on the subject area. Ralph P. Alex, "How Are You Fixed for Blades? The Saga of the Helicopter, Circa 1940-60," published in *The Age of the Helicopter, Vertical Flight*, National Air and Space Museum, 1984.)

Dayton, Ohio
January 15, 1909

Like all novices, we began with the helicopter (in childhood) but soon saw that it had no future and dropped it. The helicopter does with great labor only what the balloon does without labor, and is no more fitted than the balloon for rapid horizontal flight. If its engine stops it must fall with deathly violence for it can neither float like the balloon nor glide like the aeroplane. The helicopter is much easier to design than the aeroplane but is worthless when done.

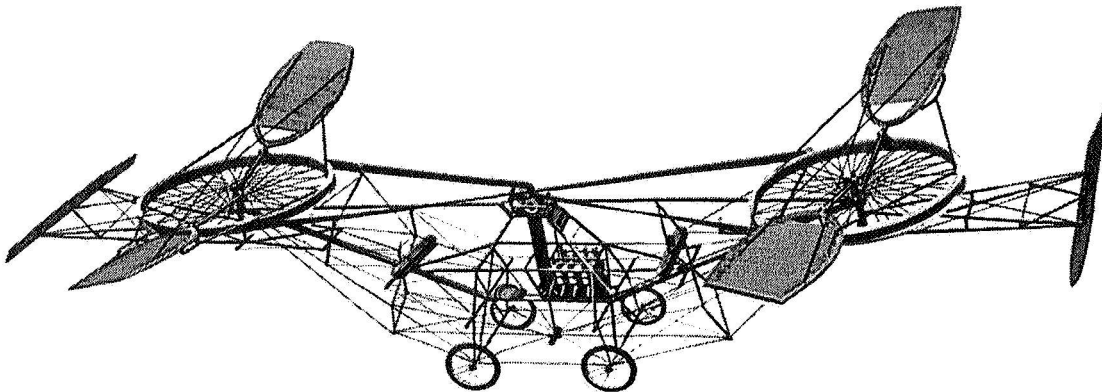
- Wilbur Wright

When Wilbur Wright wrote that article, he was already wrong, because the first free flight by a helicopter had already occurred. Most people didn't know about the 20 second flight by Frenchman Paul Cornu on November 13, 1907. Some estimate it was about the 40th attempt to fly a helicopter. Only a couple months earlier, on September 19, 1907, the Breguet brothers' helicopter had flown to a 2 foot height for approximately one minute but it was "restrained" by four helpers at the four corners of the aircraft because it had no means of control. Other inventors followed: Jacob C. H. Ellehammer of Denmark hovered with several short hops in 1912; Raul Pateras de Pescara of Spain first flew a counter-rotating 16-bladed helicopter for one minute on January 11, 1922 with subsequent flights of 10 minute duration & distances of 800 yards; an American Henry Berliner flew both a coaxial helicopter and a side-by-side rotor helicopter in 1920 and 1922; George de Bothezat, who had his "Helicopter Rotors Theory" published by NACA in 1916, flew for one minute 41 seconds on December 18, 1922 in a quad rotor helicopter financed by the U. S. Government; Etienne Oehmichen flying first in 1923, flew a one kilometer circuit on May 4, 1924. By 1936, A Breguet-Dorand helicopter set FAI records of 44 km distance, one hour 2 minutes 50 seconds endurance and 108 km/hr speed. (Jean Boulet, *History of the Helicopter as told by its pioneers, 1907-1956.. Editions France-Empire, 1982.*)

"FIRST" HELICOPTER FLIGHT

Paul Cornu

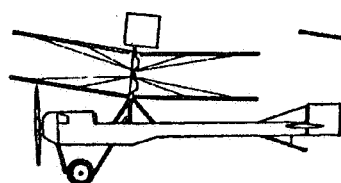
1907



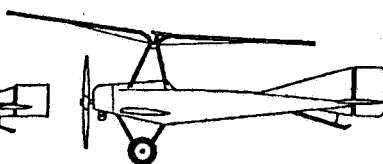
The man who jump started the helicopters was the Spaniard Juan de La Cierva. He developed the Autogiro (his proprietary name) in England during the 1920s. Cierva invented the articulated rotor which has both vertical and horizontally hinges near the blade root end. The concept, which reduces blade moments at the *rotating* hinge to zero, was a defining element in the invention of the first practical helicopters. The figure shows some of Cierva's Autogiro designs. The first three aircraft shown were unsuccessful because the design provided *restraints* to the blade which caused the aircraft to roll over during take-off. Eventually, he found the articulation key to success, then added blade pitch and rotor tilt controls while establishing world wide patents. The C-8 became the catalyst for a partnership between the American Pitcairn and Cierva on August 14, 1929, hence the Pitcairn Cierva Autogiro Company of America (PCA) was formed which further developed the patents. PCA would licensed the patents to other companies. A design manual was supplied to the licensee. (Juan de la Cierva, *Engineering Theory of the Autogiro*, Pitcairn Cierva Autogiro Company of America, 1930; and Frank Kingston Smith, *Legacy of Wings, The Harold F. Pitcairn Story*, Jason Aronson, 1981.)

Cierva's concept of flight was that with the a rotor powered by the "wind," the auto gyro would be the safest type of aircraft to fly. One of the ironies of aviation is that Cierva was killed in the crash of an *airplane* in 1936. He probably never realized that in perfecting the Autogiro rotor, he gave the world the first practical helicopter rotor. (Giorgio Apostolo, *The Illustrated Encyclopedia of Helicopters*, Arnoldo Mondadori Editore S. p. A. Milano, Italy, 1984.)

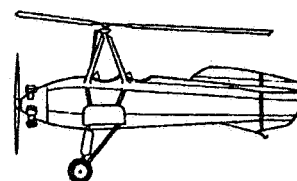
DEVELOPMENT OF LaCIERVA AUTOGIROS



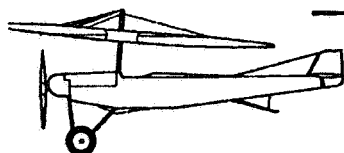
1920 - Cierva C-1, with two rotors.



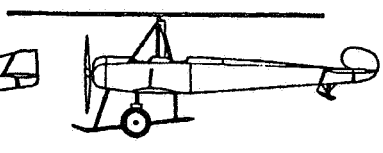
1923 - Cierva C-4.



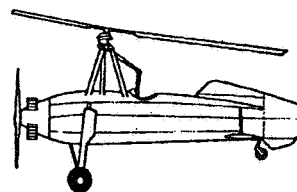
1929 - Cierva C-19, two-seater.



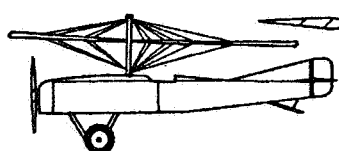
1921 - Cierva C-2.



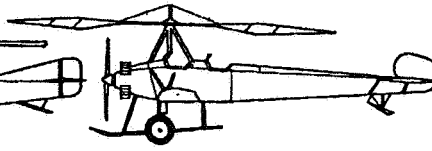
1924 - Cierva C-6.



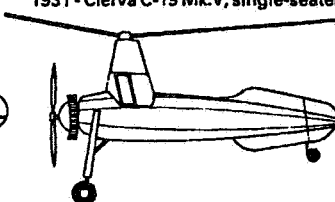
1931 - Cierva C-19 Mk.V, single-seater.



1922 - Cierva C-3.



1927 - Cierva C-8, with a two-blade rotor.

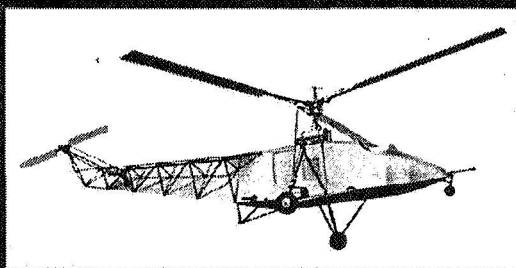


1937 - Cierva C-40, two-seater with an enclosed cabin.

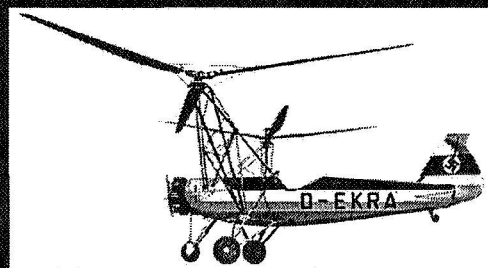
After the Autogiro, came the first practical helicopters. The Breguet-Dorand helicopter, a complicated coaxial rotor machine flew in June 1935. The vehicle vibration, dynamics and control were so marginal during early flights that the aircraft was frequently damaged. That aircraft never saw production even though flights continued until the occupation of France. The aircraft was destroyed in a 1943 bombing raid. The first helicopters to lead to production were the Sikorsky VS-300 and the Focke Fa 61. The XR-4, a single main rotor/tail rotor aircraft, was little more than a dressed-up version of the VS-300. It was the first of over 600 aircraft built during WWII in three models. Hanna Reitsch flew the Fa 61 inside of the Deutschlandhalle of Berlin during February, 1938 and inspired LaPage to design the unsuccessful XR-1. The Fa 61 with side-by-side rotors, led to the Focke Achgelis Fa 223, an aircraft nearly 3 times the weight of the Fa 61. Production facilities were built to produce hundreds of Fa 223 per month but they were bombed several times. Only seventeen aircraft survived the war. After the war, France and Czechoslovakia built Fa 223 aircraft in small quantities from surviving parts. (J. R. Smith and Antony L. Kay, *German Aircraft of the Second World War*, Putman, '72.

In the USSR, the Fa 61 apparently inspired a series of helicopters starting with the Bratukhin Omega but the successful configurations, the coaxial and single rotor designs, came from the Kamov and Mil design bureaus. By 1977, Mil had developed a large single rotor helicopter, the Mil 26, which can lift approximately 25 tons or carry 70 to 100 passengers.. For assessing scale in the figure, the pilot's cockpit of the Mil 26 is about the size of a C-130's cockpit. (Apostolo)

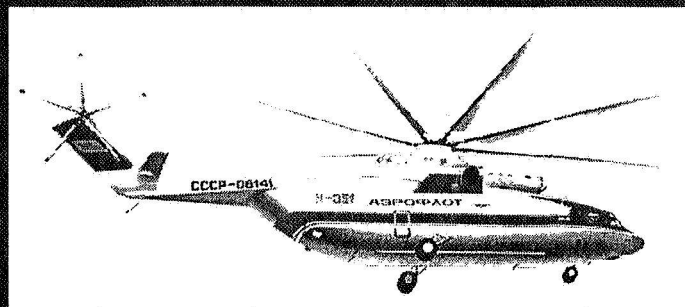
"RECENT" HELICOPTERS



VS-300 (1939)



Fa 61 (1936)

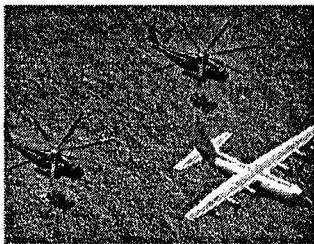


Mi-26 (1977)

The variety of military uses for helicopter have grown to surpass that of fixed wing aircraft. The first helicopters acquired by the military were used primarily for observation, search and rescue. Mission equipment was added as the size and payload of helicopters grew so that both troop transport and anti-submarine warfare became standard uses. The piston engine Bell Model 47 (military H-13) which first flew in December 1945, received civil certification in March 1946 and saw first military service in December 1946, became the litter bearer of the Korean War and an actor in a TV program called MASH. For a large number of years it was also the basic helicopter trainer in military flight schools.

Today, world wide deployment of helicopters is required. If the aircraft can not be folded or disassembled quickly for shipment in a Air Force transport, then the aircraft must be self deployable. In-flight refueling, which became the standard method of keeping Jolly Green Giants (CH-3C/E/F) on station to rescue downed pilots during the Vietnam War has been adopted to most large helicopters and to many smaller special mission aircraft. The Vietnam War demonstrated innovative means of arming transport helicopters. Today, ground attack and ground assault helicopters carry devastating firepower. The first guided missiles fired during Desert Storm were fired from attack helicopters, after a thousand-mile low-altitude dash across the desert, in order to knock out front line radar before the first air bombing assault. Special air-capable ships are now built to carry Marines and their aircraft for sea assault. In the naval environment, helicopters become mine sweepers and carry anti-ship missiles that will destroy a major vessel.

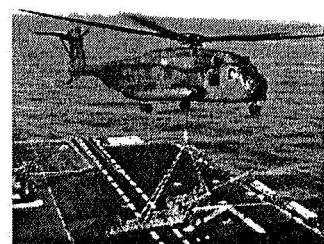
MILITARY HELICOPTERS



World Wide Deployment



Weapons Supply

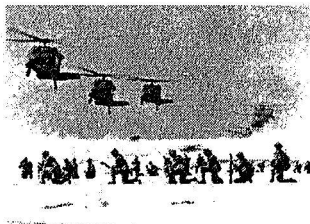


Sea Assault

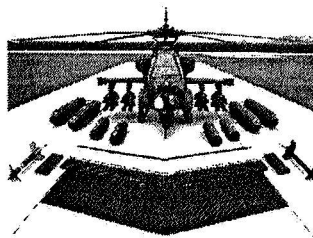


Ground Attack

Ground Assault



Mine Sweeper



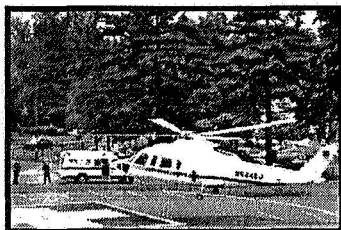
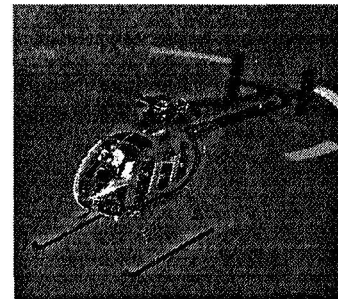
Anti Ship

Bell Aircraft began design of a helicopter in 1941, based on the 13 year private study of the philosopher Arthur Young. The company funded effort resulted in the Model 47, certified in March of 1946. The Young concept used a two-bladed "seesaw" rotor, not an articulated rotor. Cyclic control was transmitted through a stabilizer bar. Over 6000 Bell Model 47 variants were built over the following 30 years. Civilian uses of helicopters were nearly all first tried with a Model 47. A universally accepted use is that of providing emergency medical service (EMS). A popular TV program, MASH, alerted the public to EMS. A Doctor publicized the life saving benefits of providing trauma care within one hour to critical patients and an industry was born. EMS helicopters are used all over the United States and in much of Europe. Counting rescue missions from fires and ship wrecks, it has been estimated that over a million people owe their lives to the use of a helicopter.

Helicopters application is preferred to airplanes for some agricultural treatment. Police helicopters assist patrol cars in traffic and crowd control and in search and rescue missions. Workers are flown to off shore oil rigs around the world. Power line construction in remote areas and even maintenance of insulators is performed by helicopters. A helicopter "truck" was recently introduced to carrying logs, put air conditioners on top of buildings, and that sort of things. In Newport News, a sport helicopter has been designed and demonstrated with production imminent at a cost of about \$30,000. The Presidential and executive transport uses have been around for a long time. The one area that has been the least successful is airline use. However, new possibilities exist in the new future.

CIVIL HELICOPTERS

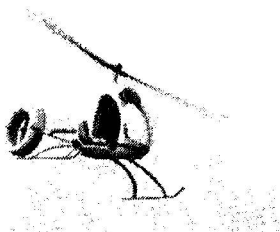
Off Shore



Emergency

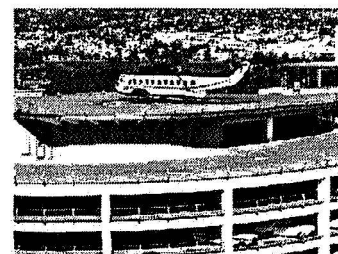
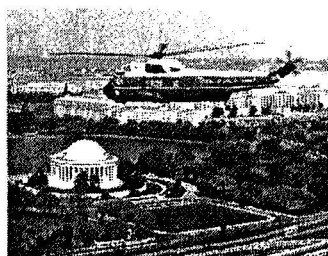
Police

Vertical
Lift



Sport

Executive



Airline

All technical areas have made progress and continue to do so because the industry has a focus on advanced technology. The interactive nature of the various elements of the helicopter resulted in frequent surprises to early designers. Early theory and experimental validation was often limited to the parameters of the aircraft just built, not to the next design. Sometimes a "new" dynamic mode was excited that never caused problems in a closely related design. The cause was that rotary wing vehicles required more integration than fixed wing designs. Starting in the '50s, the U. S. industry began developing a cadre of people who applied scientific methods to understand the interactions between unsteady airloads, blade and airframe dynamics, flight and control system dynamics. Especially important in this regard has been support of AHS graduate study scholarships and the Army's selection of rotorcraft "centers-of-excellence" on which to focus their University research. The Army also placed research staff at the three NASA research centers. From those broad activities, unique rotorcraft analysis and design tools have evolved that are more accurate, user friendly and permit more optimum designs. The revolution in computer speed, capacity, and availability, along with an integrated product approach, is now focused on reducing the cost of rotary wing aircraft. (D.P. Schrage and D.N. Marvis, "Integrated Product-Process Design-Development through Robust Design Simulation: The Key for Affordable Rotorcraft," 51st Forum of the American Helicopter Society, May 1995.)

A byproduct of the advanced technology focus is that old dreams become viable when previous limits are broken by newly developed technology.

ROTARY WING DEVELOPMENT

Technology Achievement and Challenge

- **All technical areas have made progress and continue to do so (examples)**
- **Rotary wing vehicles require more integration than conventional fixed wing**
- **Analysis / design tools have, over time, become both more "user friendly" and accurate and offer more optimum configuration**
- **Shift to computer data base permits integrated product approach (design - analysis cyclic with manufacturing / production)**
- **Old dreams become viable when previous limits are broken by new technology**

Igor Sikorsky dreamed of vertical flight. In 1909, he purchased a 15-hp Anzani engine and attempted to build a helicopter. His first attempt was unsuccessful. His second attempt, after considerable experimentation, "was nearly able to lift its own weight from the ground." He became convinced that the available technology was insufficient to build a practical helicopter. He turned his attention to airplanes, designing and building the first four engine aircraft, flying boats and amphibious craft but keep dreaming of a helicopter. In 1931, he filed for a U.S. patent on a helicopter design with a single main rotor, cyclic pitch control and a shaft driven tail rotor. The cyclic pitch control used trailing edge flaps on the main rotor blades. The helicopter became his full time focus in the spring of 1939. He made his first "tethered" flight with the 1092 lb. VS-300 helicopter on September 14, 1939 using a 65-hp Lycoming engine. Aviation power plants had matured 30 years. (Sergei I. Sikorsky, "The Development of the VS-300," *Top Technology Achievements in the History of Vertical Flight*, published by The American Helicopter Society, 1994.)

We must acknowledge that it was the light weight reciprocating engine that really made the *practical* helicopter possible but it was the first generation free turbine that began to make it productive. The first generation turbine was introduced in the helicopters that carried the Vietnam war. The T-53 is the engine that powered the Vietnam ambulance helicopter - which became the Vietnam weapons carrier, (and then the Vietnam attack helicopter). (Henry Morrow, "Helicopter Turbine Engines," *Top Technology Achievements in the History of Vertical Flight*, published by The American Helicopter Society, 1994.)

TECHNOLOGY ACHIEVEMENT

Powerplant Improvements

Light weight reciprocating engines made the helicopter possible

1st generation free-turbine turboshaft engines made helicopters productive

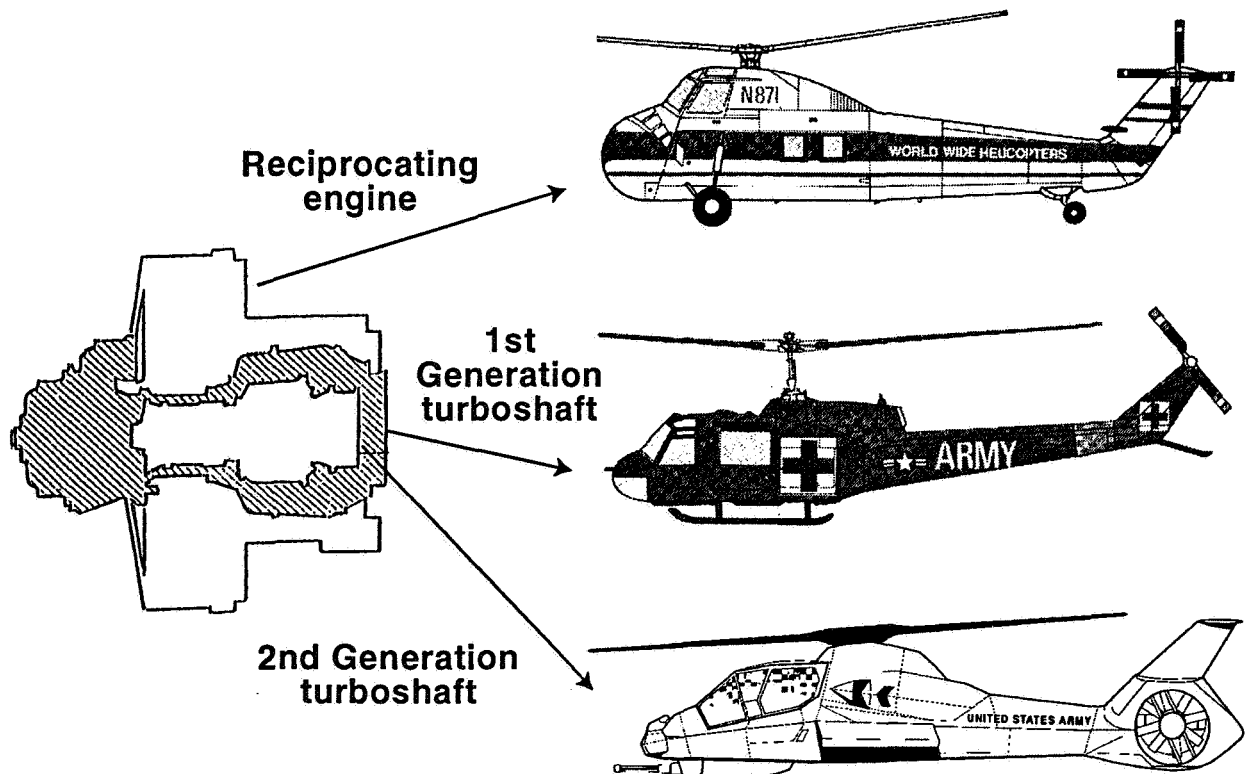
2nd generation turboshaft engines made helicopter efficient

	Reciprocating	1st Generation	2nd Generation
Engine weight/ Aircraft gross weight	0.12	0.04	0.02
SFC, lb fuel/HP/HR	0.45	0.65	0.45

A second-generation turbine engine, derived from the Modern Technology Engine (MTE) Program, is installed in the current Sikorsky-Boeing Comanche (RAH-66). That engine now has fuel consumption rates typical of piston engines along with another step reduction in the actual weight. In comparing the size of specific 800 HP demonstrator engines; the cross section of the second generation turbine engine is approximately half that of the first generation turbine engine; and the first generation turbine engine is approximately half that of an 800 HP piston engine. Advanced technology resulted in favorable weight and sfc impacts along with an engine volume reduction. The volume reduction reduces the airframe drag (the rotor propulsive force requirement) while increasing the rotor lifting efficiency. The impact of engine improvements are not obvious in direct comparison between different generation aircraft because the gains are absorbed by new requirements. For example, current engine installations must consider one-engine out, hot-day hover, minimum vertical rate of climb and maneuver requirements along with vehicle/engine signature and particle separation issues.

TECHNOLOGY ACHIEVEMENT

Powerplant Improvement



The safety and reliability of rotorcraft have significantly improved over time. An important change in rotor construction was a gradual change from wood, to metal, to composites. Early Autogiro blades were primarily wood and fabric with some metal fittings. Pitcairn introduced steel spars. Many early helicopters used the same techniques with a few using built-up all metal blades and others using laminated wood covered by fiberglass. At least one helicopter company fabricated their early production blades primarily from fiberglass. The early metal-component rotors often suffered from fatigue cracks. That can ruin your whole day. Today, most rotors systems utilize composites or specially prepared titanium parts as we progress toward advance composites hubs and blades. New rotor designs can now be designed insensitive to fatigue damage as a result of the inherent characteristics of composites.

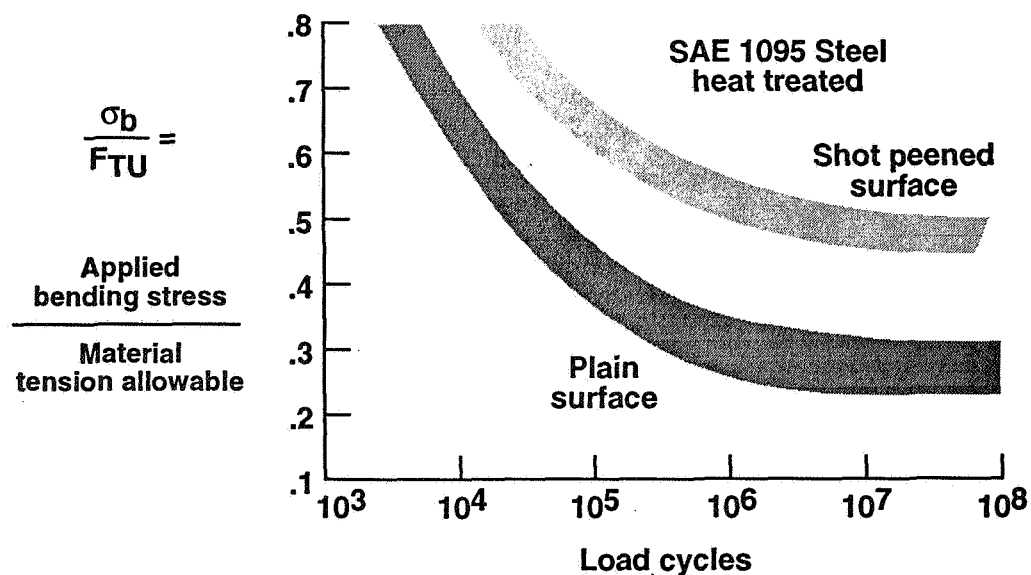
Metal component life is increasing primarily due to increased knowledge of fatigue design and test procedures as applied to dynamic components. The surface of critical metal components are now especially prepared to avoid rubbing and fretting damage. For example, the chart shows one preparation wherein shot peening, which changes the surface properties of the metal, is used to obtain a substantial improvement in the fatigue properties of the system. In the future, design will emphasis probabilistic approaches but actual component life will be "on-condition" depending heavily upon system health and usage monitoring. (Richard M. Carlson, "Reliable Dynamic Components," *Top Technology Achievements in the History of Vertical Flight*, published by the American Helicopter Society, 1994.)

TECHNOLOGY ACHIEVEMENT

Safety and Reliability

Rotor Composites: • Insensitive to fatigue

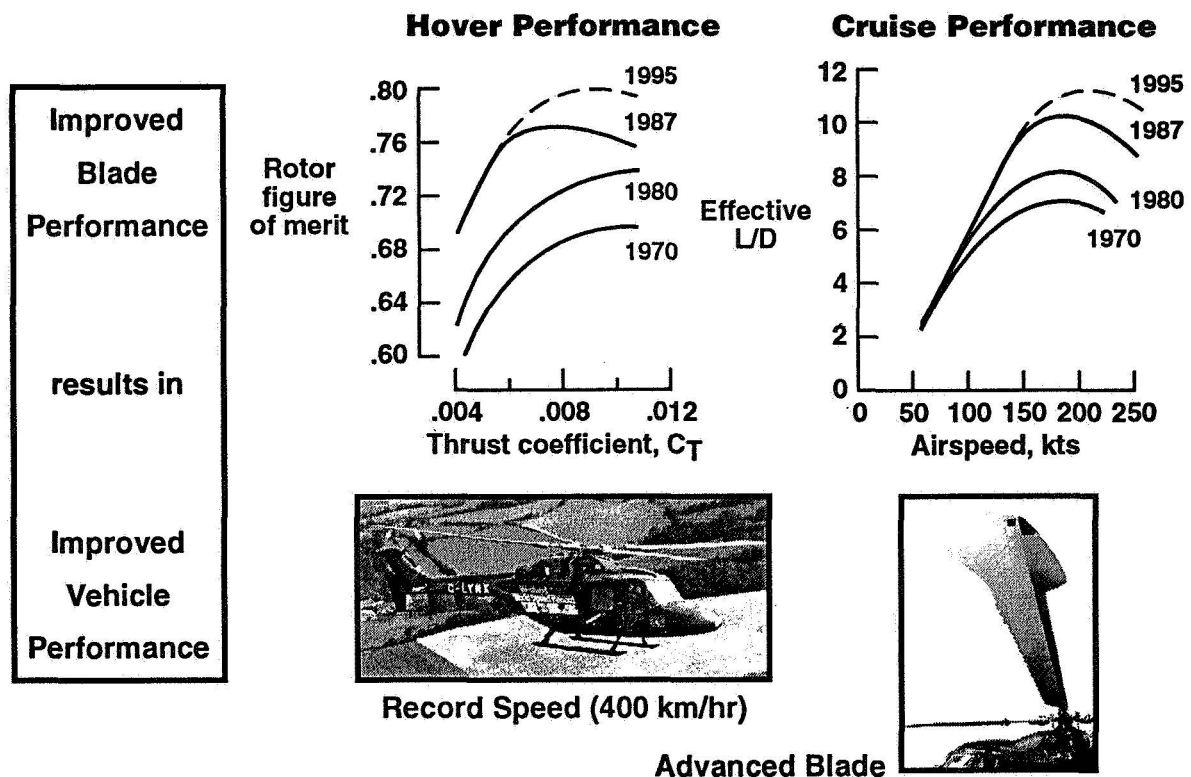
Dynamic Components: • Special surface preparation



A combination of new airfoils, more optimum planforms, greater design flexibility, and better analysis for integrating the rotor into the airframe has resulted in improved overall vehicle performance. For example, an experimental BERP blade (British Experimental Rotor Program), when installed on a Westland Lynx, set a speed record for conventional helicopters of 400 km/hour. Three versions of the EH 101 and two versions of the Lynx now use the BERP blade. These improvements occurred gradually. Since the first rotor with a cambered airfoil was installed on the CH-46, significant rotor performance improvements have occurred. The figures show that the hover figure of merit and cruise performance has increased over the years as the result of a collection of synergistic improvements. Additional improvements are expected. (Kenneth I. Grina, "Development of Helicopter Design Capability Progress from 1970 to 1993," The 1993 Nikolsky Lecture, *Journal of the American Helicopter Society*, Vol. 39, (1), Jan. 1994).

TECHNOLOGY ACHIEVEMENT

Rotors

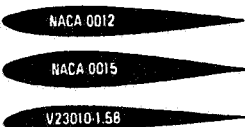
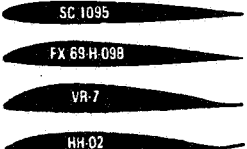
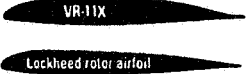


Rotor technology has made giant strides since the earliest helicopters. Most early rotors used the 0012 airfoil or an equivalent uncambered airfoil. The local velocity of a blade tip in forward flight is near sonic speed on the advancing side of the rotor and is near stall on the retreating side. These condition get more extreme as the helicopter goes faster and as the helicopter maneuvers. The rotor airfoil operates between these extremes once each revolution. The airfoil must be designed to provide the best compromise between good stall characteristics and good sonic characteristics. Because of this unique requirement, a family of special airfoils for rotory wing applications have been developed. The blade planform and twist variation can also be tailored to increase the efficiency of a rotor. The blade material improvements over time has also influence the natural frequencies and structural response to the unsteady airloads experienced.

The method of blade "articulation" has also changed over time as complex hinges and dampers give away to elastomerics and structural bending. Eventually, rotor performance will further improve as elastic articulation replaces the clap-trap of hinges and dampers still in use on most helicopters today. Analysis is being developed now that will integrate the dynamic interactions of non steady aerodynamics, non-isomeric and non-linear structures, and flight maneuvers that is required before elastic articulation can become standard on new rotors. (Alfred Gessow, "Advanced Rotor Geometries," *Top Technology Achievements in the History of Vertical Flight*, published by the American Helicopter Society, 1994.)

TECHNOLOGY ACHIEVEMENT

Rotors

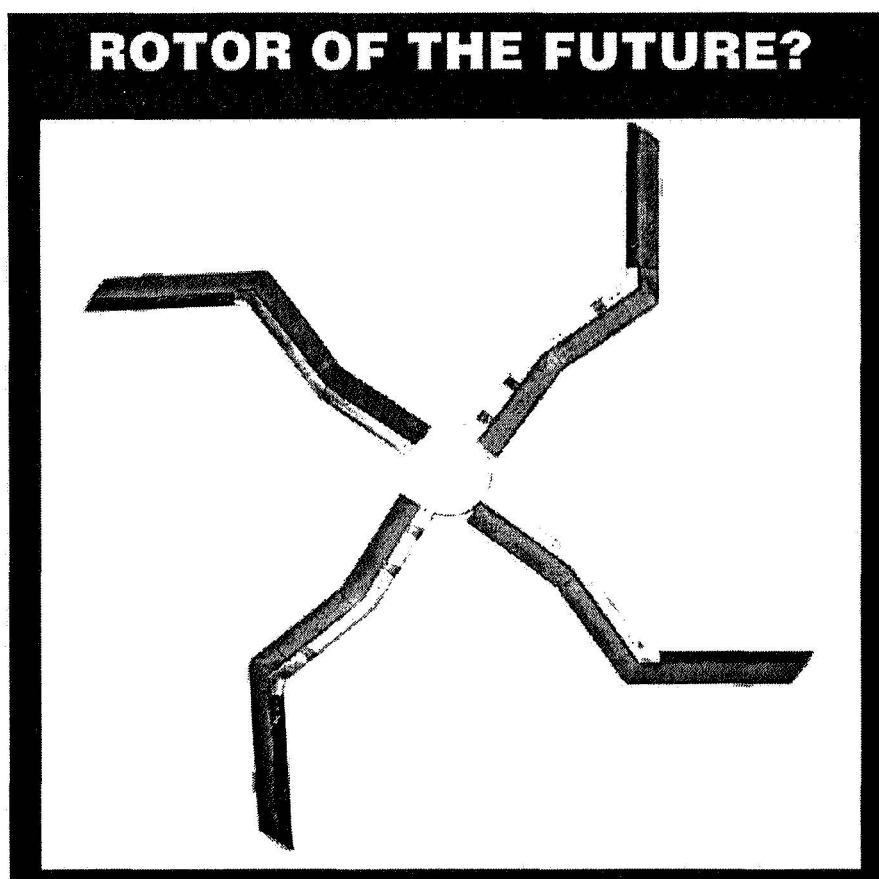
	Past	Current	Future
Airfoils			
Planform	Rectangular	Tapered Special tips	Integrated and optimized
Structure	Metal	Composite	Advanced composite
Articulation	Mechanisms • Hinges • Dampers	Composites and elastomerics	Elastic articulation

This is a McDonnell Douglas MD600N, a new 7-passenger aircraft that is ready for production. It is the great grandchild of the Light Observation Helicopter of the pre-Vietnam era. The family resemblance to the OH-4 helicopter is probably the only thing unchanged. The designers eliminated the tail rotor by substituting a pneumatic device called the NOTAR[®], enlarged the airframe, installing the latest version of the Allison 250-C47 engine (700 shp. derated to 575 shp), increased the number of blades from 4 to 6, and slowed the main rotor a little. The result is a 4150 lb aircraft capable of: picking up 140 percent of its empty weight; hovering at 10,500 feet; a sea level climb of 1,700 ft/min.; a maximum speed of 175 mph with a cruise speed of 154 mph over a 446 mile range. They now have a very fast, efficient, low operating cost, seven passenger aircraft which is also more than 7 dB below the FAA noise requirement. Similar technology is available across the industry in a variety of vehicle classes. The industry now recognizes that low noise designs may actually be more efficient. (Evan A. Fradenburgh, "The First 50 Years Were Fine . . . But What Should We Do for an Encore?" The 1994 Nikolsky Lecture, *Journal of the American Helicopter Society*, Vol. 40, (1), Jan. 1995)



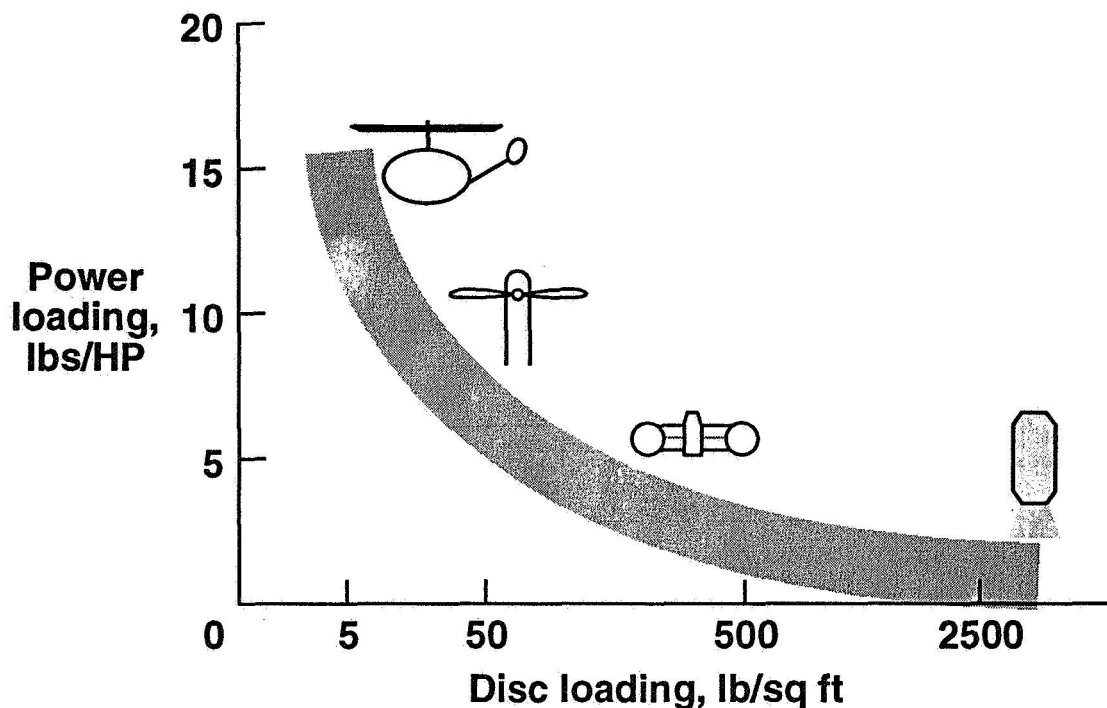
What can we expect to see in the future? This photograph shows a rotor concept that may look a little bit weird. The concept may not work today but I suggest that this is the direction rotor design will proceed in the next 5 to 15 years. Dr. Thomas F. Brooks sees this type of rotor as *the* approach to reducing overall rotor noise. This blade concept reduces blade vortex impact and sonic shocks, the two sources of rotor "blade-bang" noise notable with the Vietnam era Huey helicopter still flying. The promise of this concept, augmented with leading edge spoilers and a trailing edge device, is another step increase in vehicle capability. Aerodynamic, vibration, and noise control devices on the blades will include active controls and smart structures. (R. Barrett, *Intelligent Rotor Blade Actuation through Directionally Attached Piezoelectric Crystals*, University of Maryland Thesis, 1993.)

The elements of a helicopter include a fuselage structure, an engine, a transmission and drive train, controls, mission systems and the rotor(s) system. Considering the advanced technology in development within the aerospace industry, the rotor and perhaps the drive system are probably the principal elements of the helicopter that requires a unique research focus. Assuming rotorcraft application efforts continue, broad based research in materials, structures (including smart structures), propulsion, electronics, control theory (and integrated design), mission systems and production will be applied to the helicopter. Much of it will be applied before airplane applications (principally because of the relative scale of operations) but always at least parallel to airplane developments.



A helicopter may be the first aircraft to actually hover but a very large number of Vertical Take Off and Landing (VTOL) aircraft have been conceived, some built and flown, but only a hand full have been successful. In comparing VTOL types, it is appropriate to note that the helicopter is only a short segment on a curve of continuous VTOL concepts. The figure compares power loading versus disc loading for a variety of hovering vehicles ranging from helicopters to a simple jet engine hovering device. Helicopters, typically from 5 to 14 lb/sq. ft disc loading, enjoy the high hover efficiencies required for long duration hover or low speed maneuvers. As may be evident from the figure, one way to proceed into forward flight is simply to tilt the lifting device, providing a vertical plus a horizontal component of lift. It should be pointed out that only aircraft that cluster on the two ends of the power loading/disc loading curve (the helicopter and the jet VTOL) have gone into production to date. (D.P. Schrage, "The Rotary Wing Aircraft Conceptual Design Process, Technical Specialist Meeting of the American Helicopter Society, April 1989.)

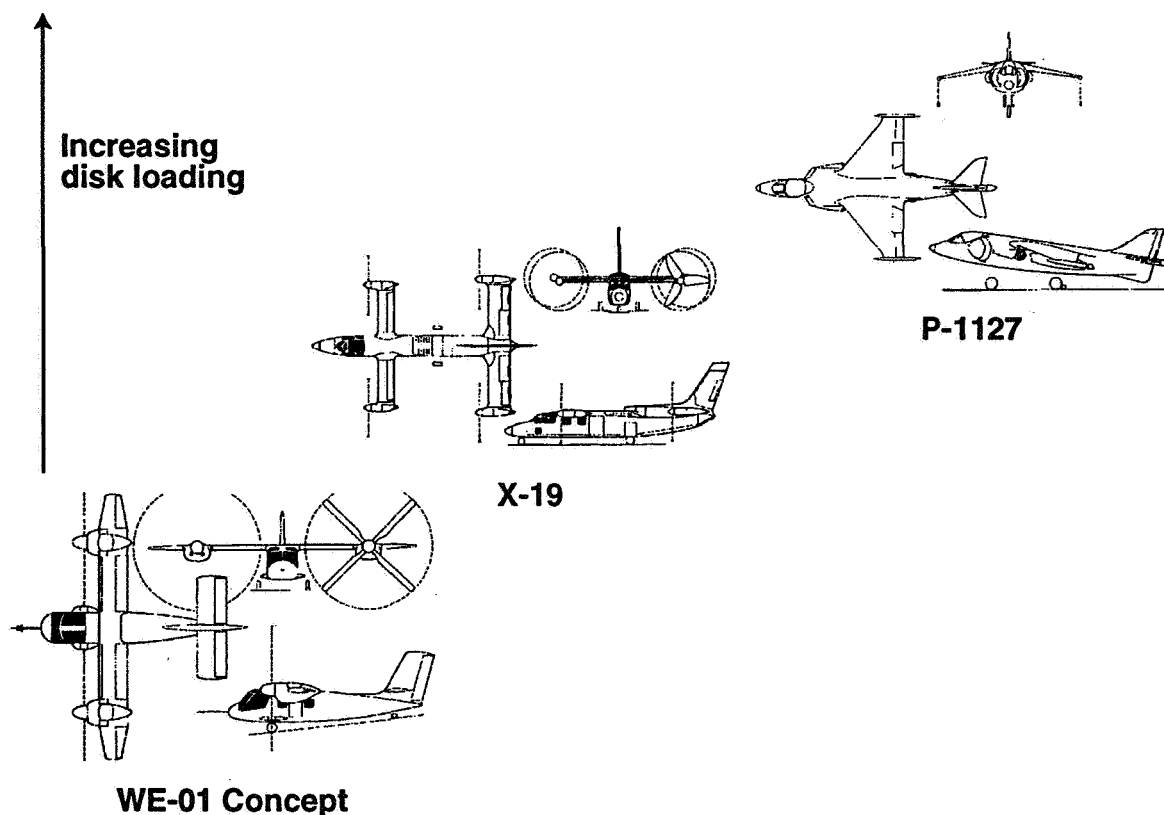
HOVER EFFICIENCY OF VTOL CONCEPTS



The figure shows three possible VTOL concepts that tilt the lifting device to convert from a hovering aircraft to one capable of forward flight. The first is an early 1950s Westland tiltrotor concept where the pylons of side-by-side rotors pivot near the wing tips to transition from hover to forward flight. The middle concept, demonstrated by the Curtiss-Wright X-19 aircraft in 1965, pivots the propeller shafts at the tips of tandem-wings. The Hawker P1127, an example of a high disc loading deflected jet concept, hovered in 1960 and converted in 1961. This concept, which balances on four columns of air from bifurcated compressor and jet exhaust nozzles, evolved into today's McDonnell Douglas AV-8B. The power loading of a jet VTOL aircraft has reached a minimum with the implication that hovering this high speed aircraft, for even a few minutes, takes a lot of fuel.

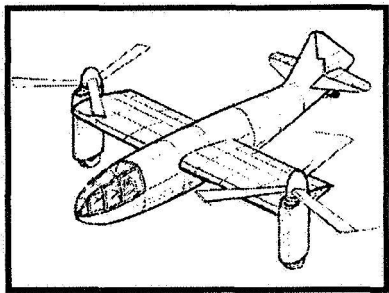
Two aircraft concepts deserve some special note. The tiltrotor has a long history of false starts. In the middle of development troubles with the tiltrotor, the tilt wing concept burst on the scene. The tilt wing had been well researched by NASA. In both vehicles the shaft of the rotor or propeller is tilted, in the later case the shaft is fixed on the wing and the wing must be inclined to tilt the lifting device. Conceptually, both aircraft could have the same disk loading, however in practice, a conceptual tilt wing is usually designed to have up to eight times the disk loading of the tiltrotor. (R. L. Lichten, L. M. Graham, and K. G. Wernicke, "A Survey of Low-Disc-Loading VTOL Aircraft Designs," AIAA Paper 65-756, Nov. 1965.)

TILTING LIFT DEVICE

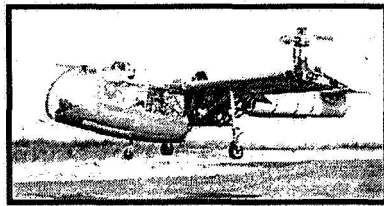


The earliest tiltrotor concepts came in the early days of practical helicopters, sometimes from the same inventors. Tiltrotor concepts in Britain and Germany were under study at the same time as early U. S. patents were granted. The Focke Achgelis Fa 269, with a rotor *behind* the wing, was designed as a fighter. This concept of a dispersed fighter never flew and most design information was destroyed. Immediately after the war, a couple of tiltrotor aircraft were built by Transcendental in the U. S. The first crashed in flight test, the second flew successfully but the company failed. Bob Lichten, responsible for the Transcendental design, moved on to Bell Helicopter where he designed the *piston-engine* powered XV-3 and became the cheerleader for the tiltrotor concept. The XV-3 demonstrated conversion from "helicopter mode" to "airplane mode" and most of the technical problems of the concept. Because of the potential offered by the concept, a great deal of research was done by NASA, the Army, Bell Helicopter and later, Boeing Helicopter on the technical issues identified in flight and through wind tunnel tests of the XV-3 aircraft. The history of the final two aircraft, the XV-15 and V-22 will be covered later. Both of these aircraft are still flying. (Robert L. Lichten, "Design Problems and Solutions for Five Types of Low-Disc-Loading, High-Speed VTOL Aircraft," presented at 7th ICAS, September, 1970 and Robert R. Lynn, "The Rebirth of the Tiltrotor," The 1992 Alexander A. Nikolsky Lecture, *Journal of the American Helicopter Society*, Vol 38, (1), Jan. 1993).

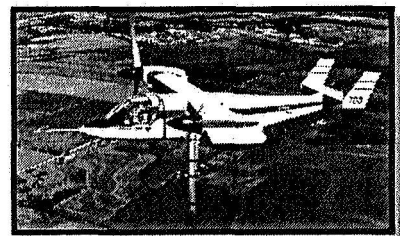
TILTROTOR



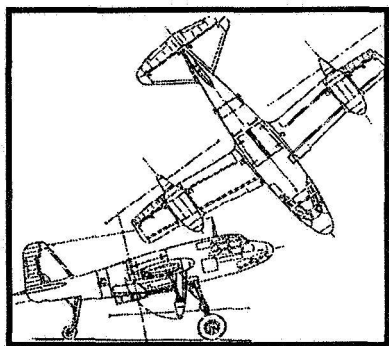
**Baynes Concept
(1937)**



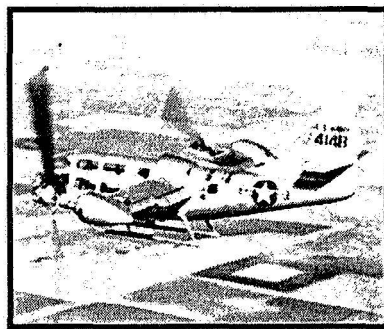
**Transcendental 1G
(1954)**



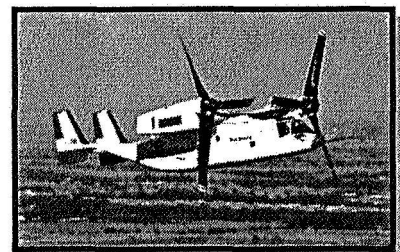
**XV-15
(1979)**



**Fa 269 Project
(1941-1944)**



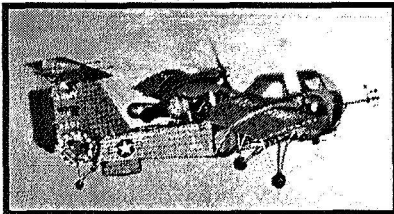
**XV-3
(1955)**



**V22
(1989)**

Turning to the competitor concept, the tilt wing aircraft offers higher cruise speeds at the cost of hover efficiency (the disc loading/power loading trade). Vertol (Boeing) built the turbine powered VZ-2 and demonstrated successful conversion from hover to forward flight. Hiller built the unsuccessful X-18 from pieces and parts of other aircraft. The concept was carried to the next higher engineering level by the turbine powered XC-142A and CL-84 aircraft. Five XC-142As were built by a partnership team of LTV-Hiller-Ryan while two CL-84s were built by Canadair. All were sponsored by the government. Each aircraft contributed to the fundamental knowledge necessary to develop a production tilt wing aircraft. The major handicap of the XC-142A was excessive noise in low speed flight and landing. Some minor aerodynamic/dynamic issues needed to be resolved. An Air Force focus on a VTOL C-130 replacement, the Light Intratheater Transport (LIT), led to selection of the tilt wing concept in 1969 by the Air Force Development Command. Unfortunately, the Tactical Air Command wanted a jet airplane and the tilt wing concept was dead. The U. S. government investment had topped a billion (in 1995 dollars). (John Schneider, "Out of the Past-Progress? Whatever Happened to the Tilt Wing," pages 56-59, *Vertiflite*, Vol 41, No. 3, May/Jun. 1995.)

TILT WING



VZ-2 (1957)



XC-142A (1964)

X-18 (1959)



CL-84 (1965)



AF LIT CONCEPT
(1969)



In contrast, the Army valued speed but needed only a modest increase over the speed of a helicopter. The early tiltrotor vehicles were all piston engine powered and appeared limited vis-a-vis the turbine-powered tilt-wing vehicles. In addition, all prior tiltrotor vehicles had dynamics problems with solutions yet to be demonstrated at full scale. But studies showed a turbine-powered tiltrotor could provide speeds beyond the compound helicopters flying at that time and still provide most of the low speed advantages of the helicopter. NASA and the Army sponsored a joint development of a "proof-of-concept" tiltrotor aircraft, the turbine powered XV-15, which was spectacularly successful (Figure 17). Demonstrations with the XV-15 across the United States and flights with "pilot-qualified" Senators and Representatives helped sell the concept. One of the key factors of government interest has been the potential for civil/military dual use which was acknowledged early. (Raoul Hafner, "The Case for the Convertible Rotor," Tenth Cierva Memorial Lecture, *The Aeronautical Journal of the Royal Aeronautical Society*, Vol. 75, Aug., Sep. 1971.)

TILTROTOR vs. TILT WING

Tilt Wing

- 1st versions turbine powered
- 3 of 4 versions flown successfully
 - Some low speed aerodynamic problems
 - Low speed noise was excessive
 - Conventional turbo-prop cruise speeds (~375 mph)
- Air Force considered for Light Intra Theater Transport
 - Preferred choice of AFDC (developer)
 - TAC (user) wanted jet airplane

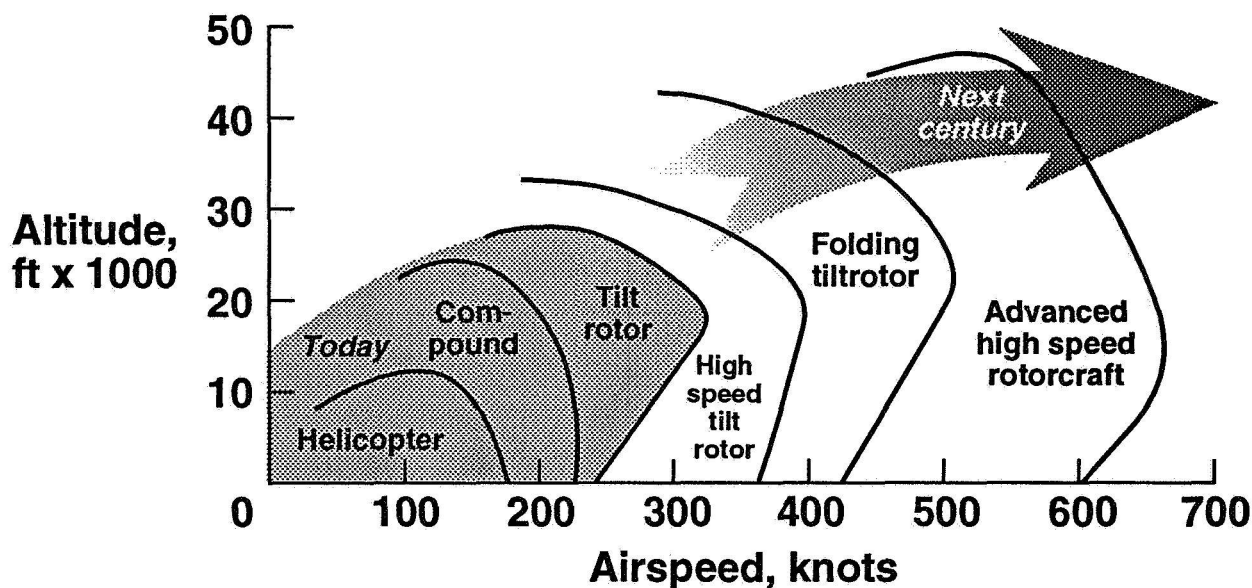
Tiltrotor

- 1st versions unimpressive
 - Piston-engine powered
 - Dynamic problems
 - Potential appeared limited
- NASA / Army began "proof-of-concept" development
 - Logical next step beyond pure and compound helicopters
 - Turbine powered XV-15
 - Successful beyond expectations
- Civil military "dual-use" potential obvious

How does the tiltrotor compare with other rotary wing types? The figure compares the flight envelope of existing and demonstration aircraft with some futuristic conceptual rotary wing types. The shaded area shows the airspeed and altitude capability of existing helicopters, compound helicopters and the two tiltrotor types currently flying (the XV-15 and V-22). (D.P. Schrage, "The Rotary Wing Aircraft Conceptual Design Process, Technical Specialist Meeting of the American Helicopter Society, Apr. 1989.)

The futuristic concepts are based on the assumption that a rotor can be designed and build that can be folded and retracted or stopped for high speed flight. A variety of concepts have been studied in considerable depth that show promise *today*, if expected technical advances are assumed. All offer the hope that a high speed aircraft can be built that will hover efficiently. (P. W. Theriault, I. H. Culver, and L. Celniker, "Considerations Relative to Stopping a Rotor in Forward Flight," paper given at 20th Forum of the American Helicopter Society, May 1964; and L. Celniker, R. M. Carlson, and R. E. Donham, "Stopped and Slow Rotor Aircraft Configuration," SAE Paper 650806, Oct. 1965; and J. D. Eisenberg and J. V. Bowles, "Folding Tiltrotor Demonstrator Feasibility Study," paper given at the 40th Forum of the American Helicopter Society, May 1985.)

ENVELOPES OF ROTORCRAFT



The compound helicopter, the aircraft concept that falls between the helicopter and the tiltrotor, showed promise, almost went into production, but fell by the wayside. As Autogyros became mature, the wings were removed. As helicopters developed, designers began to add wings and/or auxiliary propulsion with the goal of speed.

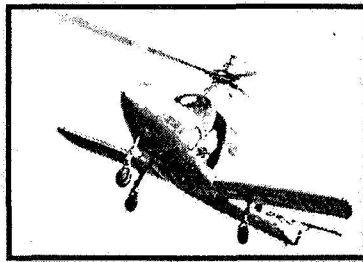
An early British compound, the Fairey Gyrodyne, used a tractor propeller on the right wing tip to set a speed record of 200 km/hr on June 28, 1948. A 525 hp Alvis Leonides radial engine drove both the propeller and a 3-bladed main rotor. The propeller also provided the necessary torque balance. A latter version, called the Jet Gyrodyne, used the Leonides to power pressure jets at the blade tips of a two-bladed rotor as well as two pusher propellers on the wing tips. This concept worked out some of the details for a later and much larger compound, the Fairey Rotordyne.

The dual engine French S.O. 1310 "Farfadet" fell by the wayside for lack of development funds due to the Algeria conflict. A nose turboprop engine and propeller was supplemented by a turbocompressor pumping air to blade tip-jet thrust units where fuel was injected. McDonnell also built a tip-jet driven aircraft, the XV-1, but the dual compressors were driven by a single piston engine. In forward flight, the engine also powered a pusher propeller. The blades were mounted on a gimbaled hub. All of these compounds had complicated dual control systems, one for "helicopter" flight, one for "airplane" flight. None of these went beyond simple exploration of the flight envelope.

COMPOUND HELICOPTERS



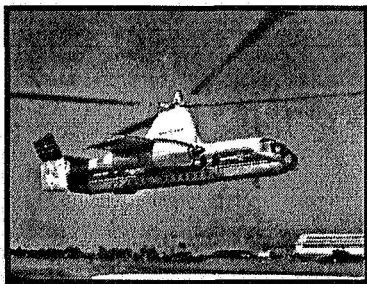
Gyrodyne
(1947)



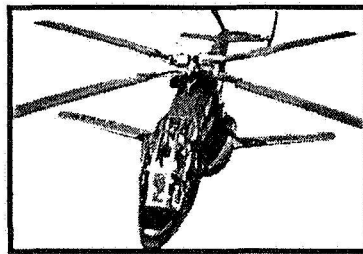
S.O. 1310
(1953)



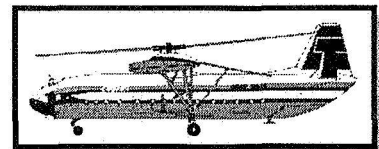
XV-1
(1954)



Rotodyne
(1957)



AH-56A
(1967)



Mi 12
(1968)

The compound helicopters that nearly saw production were the Lockheed AH-56A and the 40/48 passenger Fairey Rotodyne. A U. S. firm became a licensee for the 39,000 lb Rotodyne because of its commercial potential. Studies showed that the 160 knot Rotodyne, city center to city center, has shorter times than jet airplanes on stage lengths less than 380 nm. The Rotodyne rotor was tip-jet powered. Two 2,900 SHP Napier Eland turboshaft engines powered both propellers and a tip-jet air compressor. Fuel was added and burned at the tips for hover and low speed flight. In cruise, the rotor is in autorotation (shades of Cierva) with the propellers receiving maximum power. Selection of the tip-jet concept resulted in a 10 to 15 percent reduction in gross weight vs a rotor-transmission and tail rotor. However, the tip jets were extremely *noisy*. Fairey demonstrating the Rotodyne to the public in down town London just before the government ordered a consolidation of helicopter firms. The government canceled the program by leaving it homeless . (G. S. Hislop, "The Fairey Rotodyne," paper given at a meeting of The Helicopter Association of Great Britain and The Royal Aeronautical Society, Nov. 1958.)

The single engine AH-56A, designed as a 225 knot ground attack aircraft with unique weapon systems and sensors, was considered a priority need for Vietnam and quickly ordered into production. Flight tests were interrupted by some coupled aeroelastic/control problems. The Army requested a "cure," when the cure was slow, the Army changed requirements and canceled the program. (R. M. Carlson, R. E. Donham, R. A. Blay, and D. W. H. Godfrey, "Extending Helicopter Speed Performance," Lockheed Horizons, sixth Issue, Jul. 1967.)

COMPOUND HELICOPTERS

Issues

- **Rotodyne**
 - World wide commercial interest for airlines
 - Excessive noise from tip burning
 - Government support cancelled after public demonstration

- **AH-56**
 - High speed, agile ground attack aircraft
 - Ahead of its peers
 - Aeroelastic / control problems encountered
 - Army put production contract on hold pending "cure"
 - Army changed requirements and cancelled contract

The Russian Mi 12 side-by-side rotor helicopter (figure 21) holds the record for rotary wing size with a gross weight of nearly a quarter million pounds (105,000 kg). Each 5-bladed rotor has a diameter of 35 meters (114 ft. 10 in.). The Mil design bureau used the engine-transmission-rotor from the Mi 6/Mi 10 series, mounted them on the tips of strut-braced inverse-tapered wings attached to a large cargo fuselage. They first flew the Mi 12 in 1968 and showed it at the 1971 Paris Air Show. The M-12 was abandoned in favor of the Mi 26 which is commercially available today. Cancellation of the Mi 12 is *believed* to be due to technical issues. Considering the Russian design philosophy: "Make it simple; Make it rugged; Make it work," once serious technical issues arise, cancellation appears logical.

This lack of success with the aircraft raises the question: Is there a size limit to helicopters? The Mi 6 and Mil 10 are very successful, so the component systems were not the problem. Integration of two systems into an awkward wing-fuselage structure may be a problem. Development of the 8-bladed, 32 meter rotor for the 49,500 kg Mi 26 appears to follow conservative western practice. Perhaps the Mi 12 experiment tried to stretch the *existing* rotors too far. (Henry G. Smith, "Size Effects on the Design of Large Rotor Systems," paper given at 27th Annual Forum of the American Helicopter Society, May, 1971 and J. J. Schneider, "The Influence of Propulsion Systems on Extremely Large Helicopter Design," paper given at 25th Annual Forum of the American Helicopter Society, May 1969.)

RUSSIAN DESIGN PHILOSOPHY

Make it SIMPLE

Make it RUGGED

Make it WORK

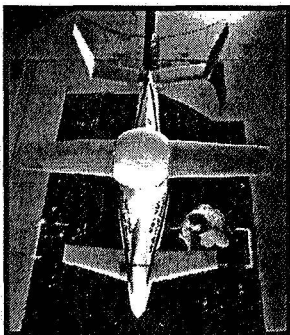
- Mikhail Leontievitch MIL

Gerald P. Herrick is the inspiration for rotary wing concepts that push the flight envelope. In 1931, he flew a biplane, the HV-1, that was equipped with a top wing that could be unlocked in flight to permit autorotation. The upper wing airfoil section was symmetrical to allow it to work in both modes. Herrick persevered and by 1937 he successfully converted the HV-2A from airplane flight to autorotation. The HV-2A hangs from the ceiling in the Garber facility in Silver Hill, MY today.

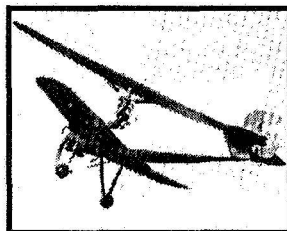
The concept of a "wing" that would provide lift either rotating or non-rotating has led to at least three additional concepts. The first, the Rotor Wing concepts, started with a symmetric delta wing wherein extended wing "tips" became the rotor blades. (The third blade is added to the forward spike of the delta). Two offshoots of the delta follow logically. The first, a 4-bladed rotor (4 wing panels) called the X-Wing. The second, a 2-bladed rotor (2 wing panels) termed the Canard Rotor Wing (CRW). Model tests have determined the basics of all three configurations.

(R. M. Carlson, R. E. Donham, R. A. Blay, and D. W. H. Godfrey, "Extending Helicopter Speed Performance," Lockheed Horizons, Sixth Issue Jul. 1967; and L. Ludi, "Composite Aircraft Design," paper given at 23rd Forum of the American Helicopter Society, May 1967; and R. J. Huston and J. P. Shivers, "A Wind-Tunnel and Analytical Study of the Conversion from Wing Lift to Rotor Lift on a Composite-Lift VTOL Aircraft," NASA TN D-5256, 1969.)

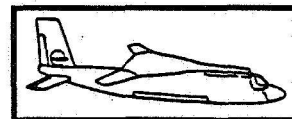
STOPPED ROTORS



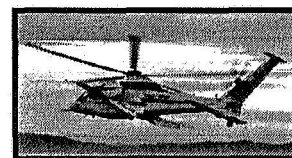
**Canard Rotor Wing
Concept (CRW)**



**Herrick HV-2A
(1937)**



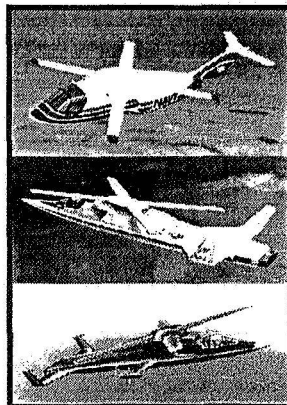
**Rotor Wing Concept
(1967)**



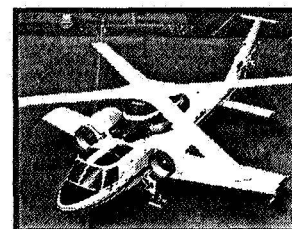
RSRA



**Tunnel Tests
(1993)**



X-Wing Concepts



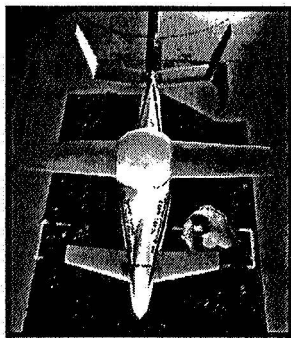
**X-Wing on RSRA
(1986)**

The X-Wing concept, coupled with circulation control, was the subject of considerable R&D effort by the Navy and NASA. A flight demonstrator X-Wing was built and installed on the Rotor Systems Research Aircraft (RSRA) in the late 1980s. The program ran into a combination of practical issues that led to termination, the coupling of a difficult control requirement with the lack of budget. Electronic, pneumatic, aerodynamic, and structural solutions are required before that concept can be considered viable. Navy R&D work continues at a low level. (R. J. Huston, J. L. Jenkins, Jr, and J. L. Shipley, "The Rotor Systems Research Aircraft (RSRA)," AGARD Conference Proceedings No. 233, *Rotorcraft Design*, May 1977; and A. W. Linden and J. C. Biggers, "X-Wing Potential for Navy Applications, paper presented at the 41st Forum of the American Helicopter Society, May 1985.)

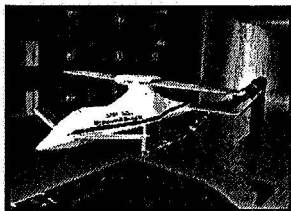
The Canard Rotor Wing (CRW) is basically a three surface airplane. The center surface operates either rotating or fixed. The CRW was tested in a Langley tunnel during 1993 and continues to be the subject of substantial industry R&D efforts.

Some external aerodynamic details need to be fixed in order to approach excellent performance in both configurations. For example, both the X-wing and the CRW use airfoils with front-to-rear symmetry. Somehow, both ends of the airfoil must use some mechanism (mechanical or pneumatic) to obtain the full Kutta condition of smooth flow from the "trailing edge," no matter which way the external flow.

STOPPED ROTORS



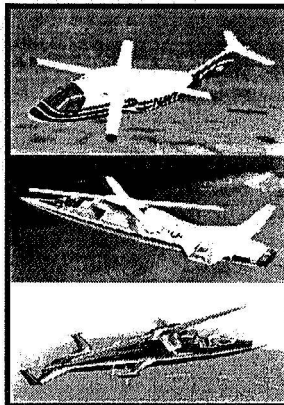
**Canard Rotor Wing
Concept (CRW)**



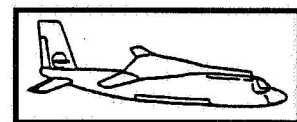
**Tunnel Tests
(1993)**



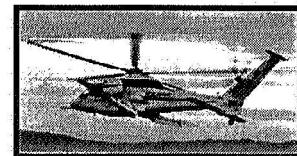
**Herrick HV-2A
(1937)**



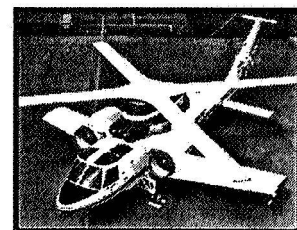
X-Wing Concepts



**Rotor Wing Concept
(1967)**



RSRA



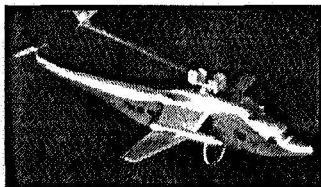
**X-Wing on RSRA
(1986)**

In the quest for efficient hover performance *and* high speed flight, an alternative to stopping the rotor and using it as a wing is to vary the geometry of the rotor in-flight so as to remove it from the airflow. One concepts that would give that result is the "roll up" rotor. The rotor imitates a tape measure & is retracted into the hub.

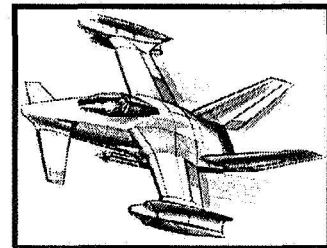
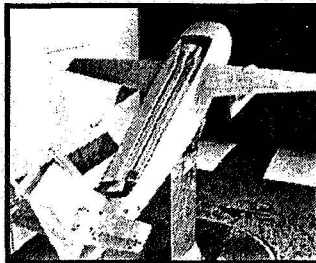
One approach to rolling up the rotor is nicknamed the "rag" rotor. Hovering test with a "rag" rotor were done at Langley in the late 1960s. The flexible rotor blade evaluated had a fabric airfoil surface fastened to cables (or flexible rods) at the leading and trailing edges. A tip weight with a stabilizer vane bridged the outboard end of the cables. The inboard end of the blade was connected to a collective pitch mechanism. The spanwise variation of the blade chord is in the shape of a catenary, so that the centrifugal force of the blade tip maintains the fabric in tension during rotation. Essentially, the blade has no static flapwise or torsional stiffness and the interaction of aerodynamic and centrifugal forces determine the behavior of the blade. The experimental limitation on the rotor was basically luffing, i.e., sail boat luffing. Analysis indicated that the most efficient way to eliminate luffing would be to add chordwise stiffeners (sail battens?) which would still permit the blade to be retracted. Research was halted at that point. However, adding battens opens the possibility of active control-smart structures battens which could control blade camber, local blade pitch and give excellent performance. A concept abandon becomes feasible again with 1990's technology. (M. M. Winston, "An Investigation of Extremely Flexible Rotors," NASA TND-4465, 1968 and "A Hovering Investigation of an Extremely Flexible Lifting Rotor," NASA TND-4820, 1968.)

VARIABLE GEOMETRY ROTORS

Model Scale



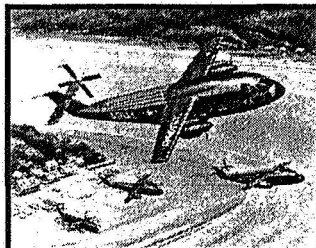
Roll Up Rotor Concept



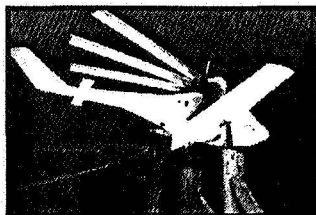
Stopped/Stowed
Rotor Concept



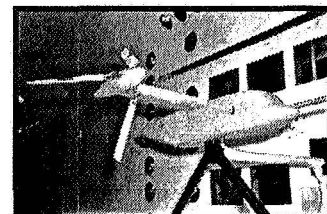
Hover Tests



Retractable Rotor
Concept (1968)



Full Scale



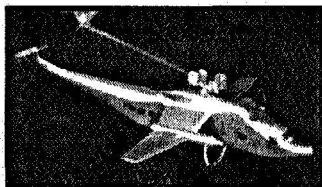
Tunnel Test

The remaining approaches to retracting and stowing a rotor have been well investigated over the years. Model and full scale tunnel tests of stopped rotor systems for compound helicopters and tiltrotor aircraft have been successful with no "show stoppers." Of the two concepts, the tiltrotor approach appears to be the most benign where the rotor is slowed and stopped, much like feathering a propeller, and then folded into a nacelle. The "horizontal rotor" stop and fold approach does have a variety of load variations that must to be successfully navigated. (W. D. Jepson and R. G. Carlson, "Wind Tunnel Investigation of a High Speed Stowed Rotor Aircraft," SAE Paper No. 680280, given at the SAE Air Transportation Meeting, 1968; and J. A. DeTore and T. M. Gaffey, "The Stopped-Rotor Variant of the Proprotor VTOL Aircraft," paper given at the AIAA/AHS/VTOL Research, Design and Operations Meeting, Feb. 1969.)

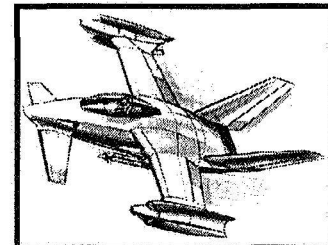
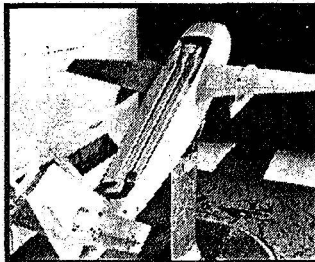
All convertible aircraft require a convertible engine. Dedicating an engine to only a single mode of flight is unacceptable. NASA recognized this years ago and built a convertible TF-34 engine. The process involved modifying a full scale engine to permit either jet power or shaft power extraction or suitable combinations of either. The convertible features of the modified engine were then demonstrated on a ground test stand. This technology is now on the shelf. (K. L. Abdalla and A. Brooks, "TF34 Convertible Engine System Technology Program," paper given at the 38th Forum of the American Helicopter Society, May, 1982; J. C. Gill and J. D. Sauer, "Convertible Engines for Fold Tilt Rotor Aircraft and ABC Rotorcraft," paper given at 38th Forum of the American Helicopter Society, May, 1982.)

VARIABLE GEOMETRY ROTORS

Model Scale



Roll Up Rotor Concept



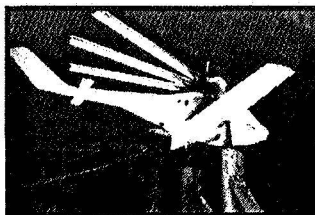
Stopped/Stowed Rotor Concept



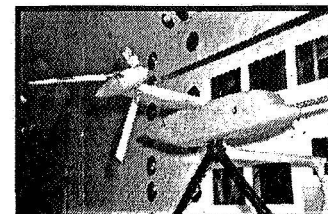
Hover Tests



Retractable Rotor Concept (1968)



Full Scale



Tunnel Test

The V-22 Osprey tiltrotor resulted from a long, unplanned, spasmodic process that reached maturity just as the USMC needed a CH-46 replacement. In December 1981, DOD set a requirement for a Joint Services Advanced Lift Aircraft (JVX) capable of multiple missions for the Army, Navy, USAF, Marine Corps and Special Operations Forces. Bell and Boeing formed a limited partnership in April 1982 and a \$1.8 billion Navy fixed-price contract (for the Marine version only) was awarded Bell/Boeing on April 28, 1986 for six aircraft. An FAA/NASA/DOD study of the potential civil applications of tiltrotor technology concluded that "tiltrotors could capture 1/3 to 2/3 of the high-density, short-haul air traffic market." A potential market greater than 1400 aircraft was projected. On June 16, 1988, the FAA established a set of goals for vertiport development and certification, air traffic control modernization, and readiness for tiltrotor demonstrations and certification. On August 12, 1988, the Bell/Boeing team and Allison announced application for civil certification of the tiltrotor aircraft and engines, respectively. On March 19, 1989, the V-22 made its first hover. On April 25, 1989, the Secretary of Defense announced the V-22 program was to be cut from the 1990 budget. Congress kept the program alive until a new administration revived the program. A 4-ship Engineering Manufacturing Development contract was signed May 3, 1993 with the first EMD aircraft scheduled to fly in December 1996. A production commitment is expected early in 1996. (Boeing Commercial Airplane Company, "Civil Tiltrotor Missions and Applications: A Research Study for FAA/NASA/DOD," NASA CR 177452, Jul. 1987 and R. J. Huston, R. A. Golub, and J. C. Yu, "Noise Considerations for Tiltrotor," AIAA Paper No. 89-2359, Jul. 1989.)



"The case for the convertible rotor" was made by Raoul Hafner 25 years ago. In his technical, economic and social study of European transportation, he found a short haul VTOL system to have the capability to take over significant portions of both rail and conventional airline traffic, as long as its primary operation was separate from CTOL airports and with independent VTOL ports and air traffic control systems. The "convertible rotor" in his analysis was an auto stabilized tiltrotor.

The 1991 US. National Transport Policy assessment found that 21 primary airports currently experience more than 20,000 hours of delay per year. The airlines cost for these delays is about \$5 billion per year. A twelve urban-vertiport network in the NE Corridor, and the 165 tiltrotor aircraft to serve it, would cost ~ \$4-6 billion and serve 12 million passenger per year. With tiltrotor transports carrying short haul passengers, the primary airports will eliminate delays due to airport capacity, a few long haul transports carrying a large number of people will substitute for large number of short haul transports carrying a few people. This is possible because, on average, commuter airplanes typically account for 30 percent of the airport usage while carrying 5 percent of the passengers. *The tiltrotor has dual use potential.*

(NASA/FAA Study of Commercial Tiltrotor Missions and Applications, Feb. 1991; and Massachusetts Institute of Technology, *Strategic Policy Development for Short Haul Intercity Transport: The Case of Tiltrotor vs. Maglev*, Cambridge, MA Jan. 1990; and Office of Technical Assessment, *New Ways, Tiltrotor Aircraft and Maglev Vehicles*, Washington, D. C., October 1991 report to Congress.)

"DUAL-USE" POTENTIAL OF THE MILITARY TILTROTOR

- **U.S. National Transportation Policy assessment of airport congestion**
 - **Twenty-one primary airports now experience more than 20,000 hours of annual delays**
 - **Cost to airlines and U.S. business exceed \$5 billion yearly**
- **For half of the \$4 to \$6 billion cost of a single new airport**
 - **Entire network of 12 urban vertiports**
 - **Including 165 40-seat tiltrotor aircraft**
 - **"Could be installed in the congested corridor between Boston and Washington, D.C., serving 12 million passengers per year"***

**Source: NASA/FAA Study of Commercial Tiltrotor Missions and Applications, February 1991*

The NASA/FAA study that determined that tiltrotors could capture 1/3 to 2/3 of the high-density, short-haul air traffic market, also identified the international passenger demand for 40-passenger tiltrotor aircraft by world region. A 1990 business analysis performed for the Department of Commerce projected that the first decade of a civil tiltrotor program would produce:

20,000 direct jobs in the United States,
 190,000 indirect jobs in the United States,
 \$20 billion in increased exports, and
 \$125 billion increase in national economic activity.

(N. Augustine, *Report on Civil Tiltrotor to Federal Aviation Administration*, Washington, D.C., Jun. 1990; and Bell/Boeing/NASA Ames Research Center, *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market - Final Report*, Seattle, WA, NASA CR 177576, Feb. 1991; Transportation Systems Center, *Civil Tiltrotor Industrial Base Impact Study*, Department of Commerce Study, Cambridge, MA, Apr. 1988; and Hoyle, Tanner & Associates, *CTR Aircraft Feasibility Study for State of California*, Londonderry, NH, Sep. 1989; Pacific Basin Development Council, *Study of Commercial Feasibility of Tiltrotor/VTOL Technology in U.S. Pacific Insular Areas*, Honolulu, Jun. 1989; and DOT/FAA/AOR-100/93/013, *Civil Tiltrotor Northeast Corridor Delay Analysis*, Jun. 1994)

ECONOMICAL IMPACT OF CIVIL TILTROTOR

Year 2000 Market Demand for a 40-seat Civil Tiltrotor* (Passenger Service Only)	Region	Number of Aircraft
	North America	1,270
	Europe	615
	Oceania	240
	Japan	500
	Total	2,625

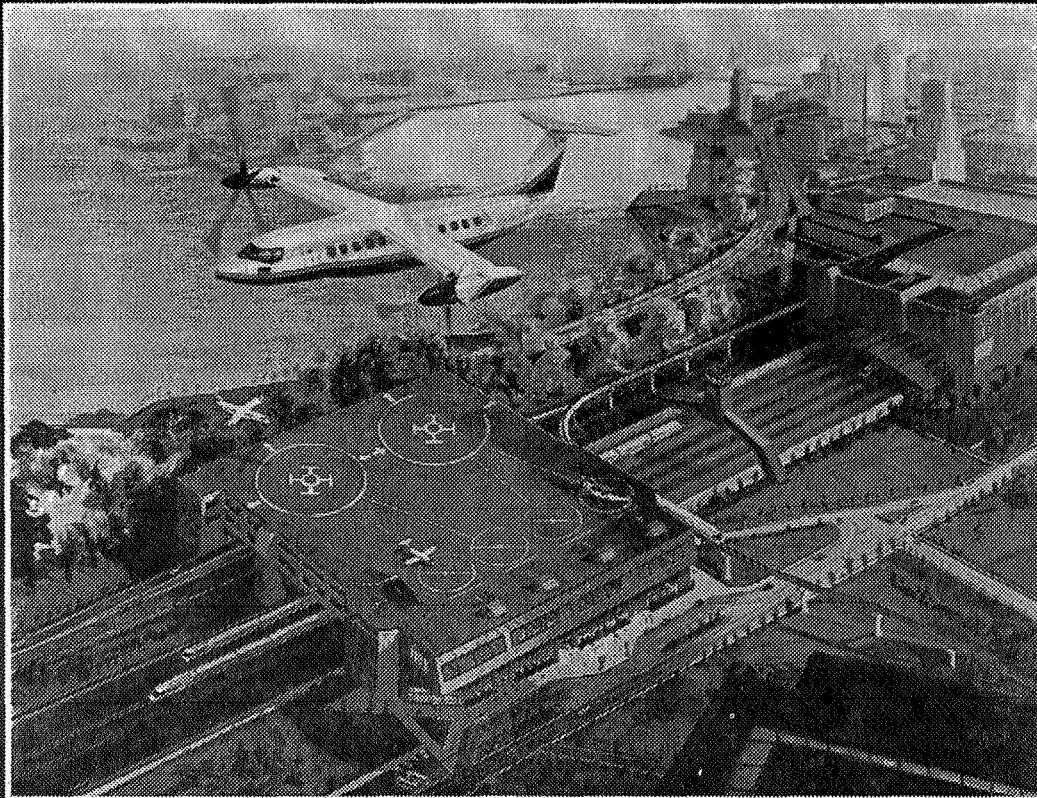
***Source: NASA/FAA Study of Commercial Tiltrotor Missions and Applications, February 1991**

A short haul civil tiltrotor infrastructure will involve: multiple intermodel vertiports chosen to complement existing road, light rail, subway and long haul air services while minimizing approach and take-off noise; an air traffic management system tailored to permit vertiport access independent of CTOL airport traffic; secure ground facilities capable of providing normal passenger support functions as well as support of vertiport operational personnel; and support of tiltrotor and helicopter aircraft and air crews.

Vertiports will add a new dimension in transportation. Selection of sites will provide strong economic stimulus for adjacent business growth and even housing. Low noise tiltrotors and helicopters *will be* "good neighbors." New jobs will be generated. Individuals will evidence pride in a community that moves forward as world leaders in aviation.

(Hoyle, Tanner & Associates, *VTOL Intercity Feasibility - Executive Summary for Port Authority NY & NJ*, Londonderry, NH, Jun. 1987)

SHORT HAUL (CIVIL TILTROTOR) INFRASTRUCTURE



Conclusions and Observations about The Future of Rotorcraft.

Rotary wing aircraft will exist in many forms in the future. The range of uses will continue to increase. The number of helicopters will increase and civil tiltrotors will become familiar in both military and civilian applications. External forces will act to push down the cost of design, manufacture, and operation of rotary wing aircraft.

Many "lifting" jobs will continue to be done by a helicopter because they can not be done by anything else at a reasonable price. The low-disk-loading helicopter will continue to be the most efficient vehicle for operations into restricted areas and for low speed flight involving hover until "anti-gravity" is a reality. The laws of physics have not yet been repealed.

Helicopters and tiltrotor aircraft (and perhaps even some higher disk loading VTOL aircraft) will compete with fixed wing aircraft in short haul passenger systems when the "real cost" of the overall systems is recognized in the accounting.

Once tiltrotor vehicles become routine, some one will stop and fold the rotor (or just reel it in) and the aircraft, at the same power level, will gain 100 knots. A new revolution in transportation will begin.

The march of technology will not leave rotary wing vehicles behind. Generic technology advances in electronics, aerodynamics, propulsion, power, structures and so forth, will be integrated into the latest rotary wing designs.

The revolution in low cost electronics, coupled with the Global Positioning Satellite System, offers a promise that cost will also decrease. When the reliability of electronics system is acceptable, automated flight control and navigation systems will permit push-button personal travel from grandmother's house to urban neighborhoods by low-cost rotary wing vehicles. When fuel cell technology permits the development of hypercars, visionaries will apply fuel cells to rotary wing vehicles.

(AUTHOR'S NOTE: The paragraphs of this paper include a brief history of the development of the helicopter to the current level of technology. The selection of pioneers and specific aircraft to emphasis are the sole responsibility of the author. Everyone in the business will recognize that I have left out major players, innovative technology, and major elements of the story.)

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Highly Nonplanar Lifting Systems

Ilan Kroo, Stanford University
John McMasters, Boeing Commercial Airplane Group
and Stephen C. Smith, NASA Ames Research Center

Transportation Beyond 2000:
Technologies Needed for Engineering Design

September 26-28, 1995

Outline

This paper deals with nonplanar wing concepts — their advantages and possible application in a variety of aircraft designs. A brief review and assessment of several concepts from winglets to ring wings is followed by a more detailed look at two recent ideas: exploiting nonplanar wakes to reduce induced drag, and applying a "C-Wing" design to a large commercial transport. Results suggest that potential efficiency gains may be significant, while several non-aerodynamic characteristics are particularly interesting.

Outline

I. Introduction and Background

II. Some Results: What Is Possible?

III. A Closer Look At Two Concepts

- 1. Exploiting Nonplanar Wakes**
- 2. A Very Nonplanar Wing: The C-Wing Concept**

IV. Conclusions and Postscript

Introduction

Nonplanar wings include configurations such as biplanes, box-planes, ring-wings, joined wings, and wings with winglets. Apart from configuration differences related to stability and trim, variations in nonplanar geometry represent one of the few major differences in aircraft conceptual design.

Such designs may be of interest because of their potential for lower vortex drag at a fixed span, a key constraint for many aircraft, including very large commercial transport concepts. However, several non-aerodynamic features are of interest as well including effects on stability and control, characteristics of wake vortices, and structural implications of the nonplanar design.

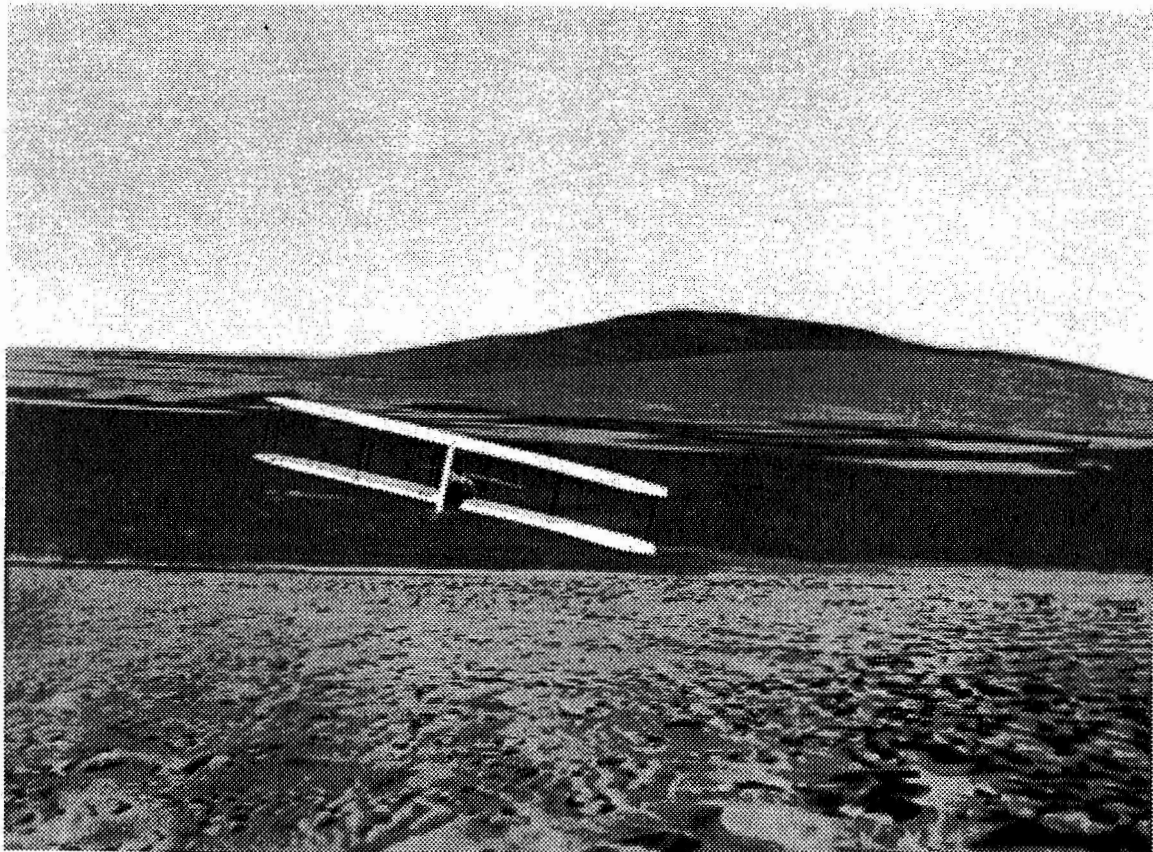
This paper reviews some of the concepts that have been pursued and discusses some of their possible advantages or disadvantages. We consider the potential of some of the concepts to improve performance incrementally or to change the configuration significantly.

Nonplanar wing concepts may be divided into a few categories based on their primary geometric or aerodynamic characteristics. These include:

- Multiplanes (e.g. biplanes, triplanes)
- Closed Systems (box planes, ring wings)
- Strut-Braced Systems (Lifting struts, joined wings)
- Nonplanar monoplanes (wings with winglets and other tip devices)
- Planar wings with nonplanar wakes (Crescent wings, Split-tips)

Examples: Multiplanes

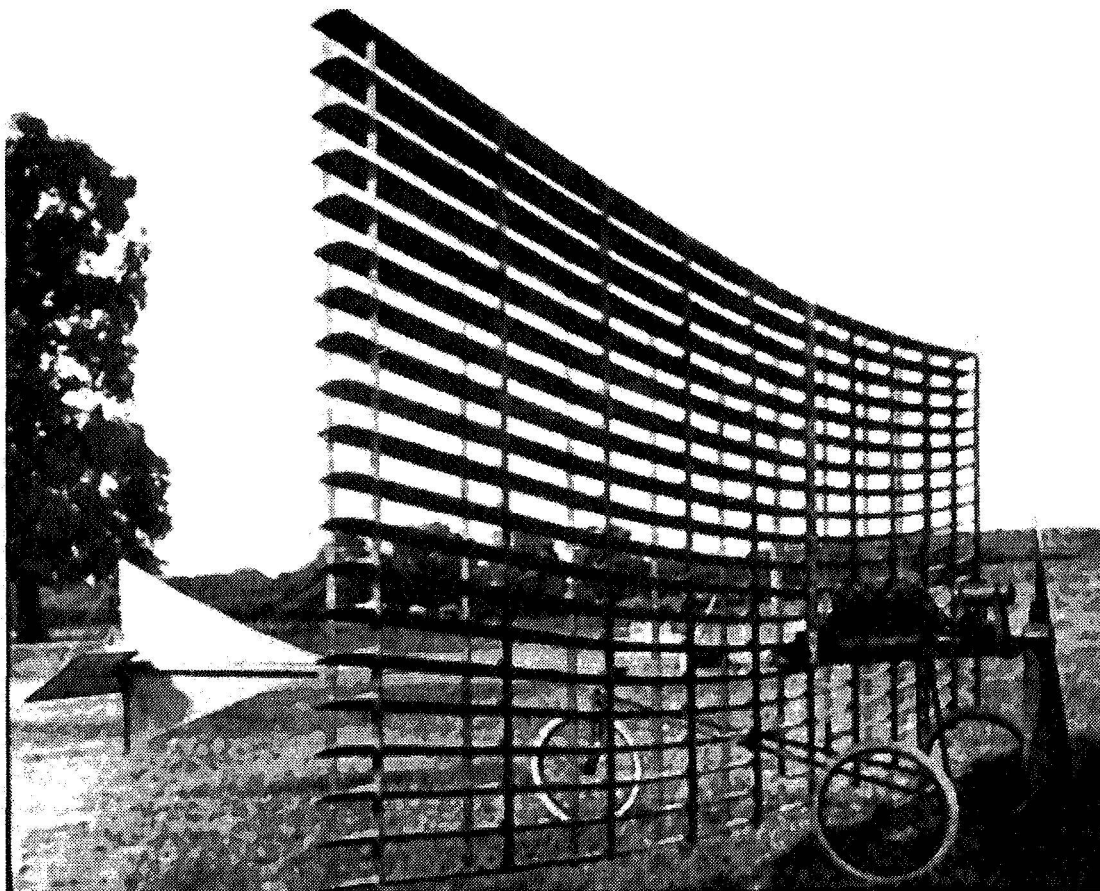
Multiplanes include biplanes such as the Wright 1902 glider shown below. Although the Wright brothers exploited the structural advantages of biplanes, rather than the lower vortex drag for fixed span and lift, their motivation was partly aerodynamic. Based on their own tests and those of Otto Lilienthal, it was apparent that at very low Reynolds numbers (typical of test conditions used by these pioneers) highly cambered, thin sections performed much better than thicker sections, making the cable-braced Lilienthal designs or the Wright biplane concepts especially attractive. Because of the low flight speeds required for Lilienthal's take-offs and landings and for the power plants available to the Wrights, the designs needed to be light and incorporate large wing areas. This requirement was satisfied well with the biplane configuration.



Examples: Multiplanes

The multiplane concept was taken to extremes by Phillips in 1904. The aircraft shown below with 20 wings would have had a high span efficiency, but the very low Reynolds number of each wing would lead to poor performance. The struts and cables of early biplane designs also led to large parasite drag, so the effects of improved span efficiency were not obvious. Several modern proposals for cantilevered or semi-cantilevered biplanes have emphasized the lower vortex drag of such configurations at the expense of structural efficiency, Reynolds number, and fuel volume.

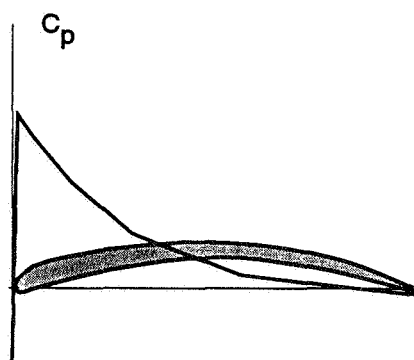
The induced drag of a multiplane may be lower than that of a monoplane of equal span and total lift because the nonplanar system can influence a larger mass of air, imparting to this air mass a lower average velocity change, and therefore less energy and drag. For a biplane, if the two wings are separated vertically by a very large distance, each wing carries half of the total lift, so the induced drag of each wing is $1/4$ that of the single wing. The inviscid drag of the system is then half that of the monoplane.



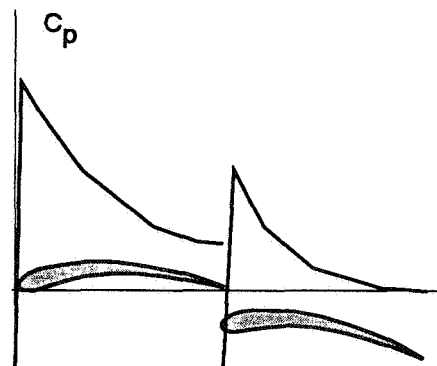
Examples: Multiplanes

In addition to the well-known advantages in vortex drag, the favorable interference between two wings of a closely-coupled biplane can be used to improve the section performance. The lower-than-freestream velocity at the trailing edge of the forward wing and the new boundary layer on the downstream wing can be exploited and some of the difficulties with lower Reynolds numbers for the biplane as compared with a monoplane can be alleviated if not turned to advantage. Gains in $C_{L_{max}}$, width of laminar drag bucket, and drag divergence Mach number at fixed t/c are possible with good multiple element section design. As an example, a single fully-laminar section (100% laminar flow on upper and lower surfaces) can support a C_L of about 0.4. A 2-element wing can be designed with an overall C_L of about 0.75. This may help to explain the preference for biplanes in the low Reynolds number world of insects.

Favorable interference for biplanes:



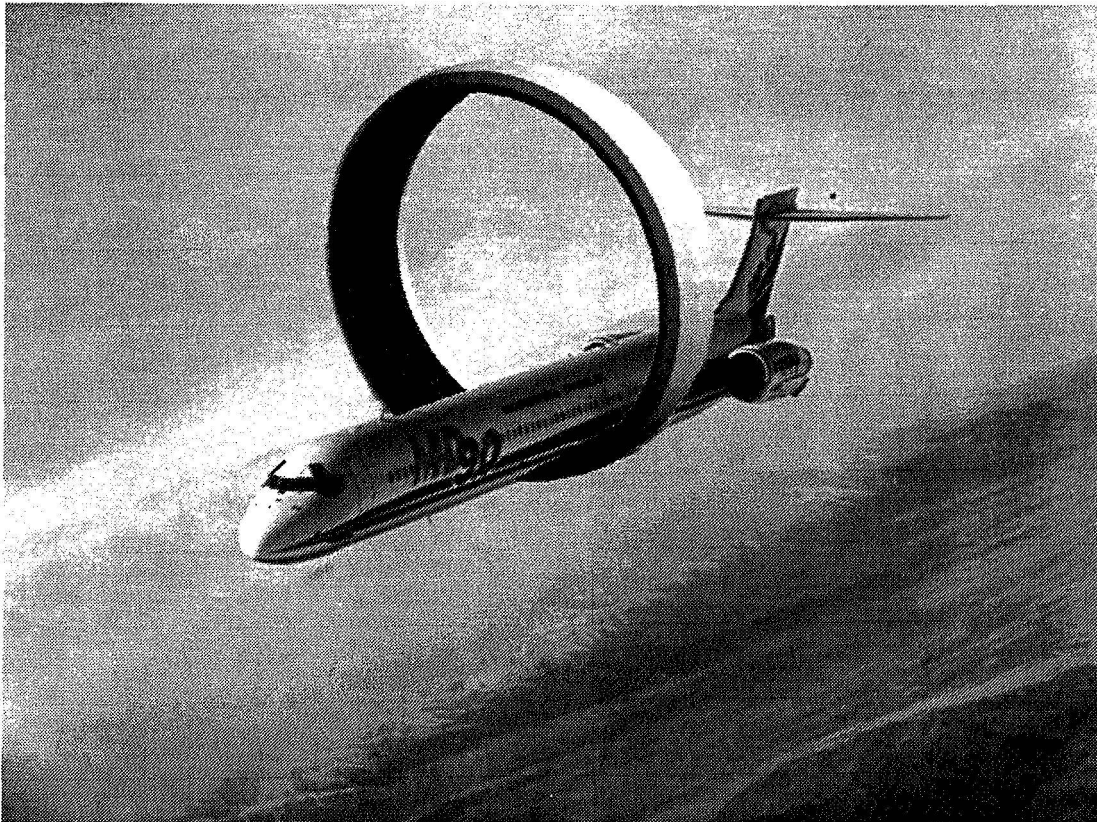
All laminar section: $C_L = 0.4$



$C_L = 0.75$

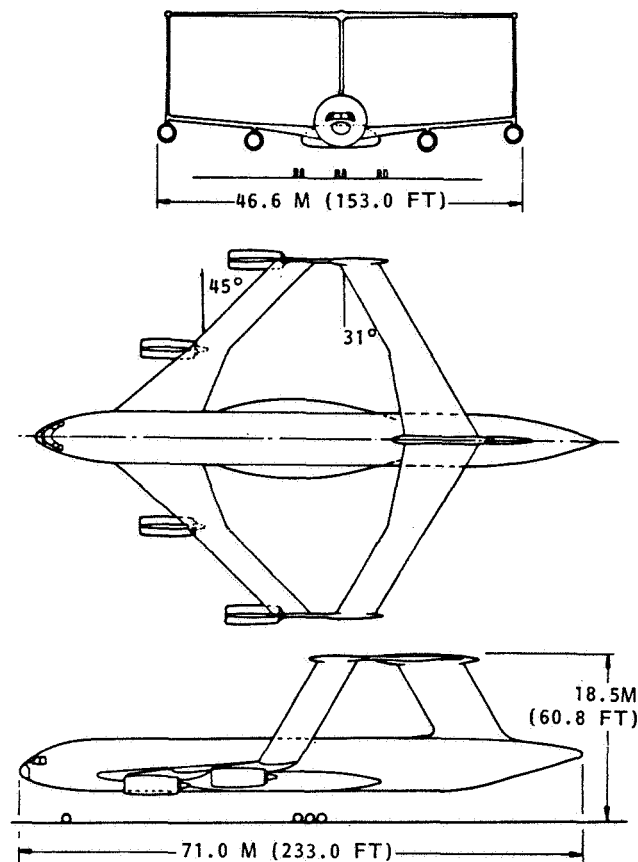
Examples: Closed Systems

The aerodynamics of nonplanar wing systems that form closed loops are very interesting. Such configurations include box-planes, ring wings, joined wings, and “spiroid-tip” devices. Wings that form closed loops, such as the ring-wing illustrated below, do not eliminate the “tip vortices” or trailing vortex wakes even though the wing has no tips. Still, the vortex drag of the circular ring wing is just 50% that of a planar wing with the same span and total lift and the concept has been studied at several organizations, including early aviation pioneers, a major aircraft manufacturer, as well as several toy companies.



Examples: Closed Systems

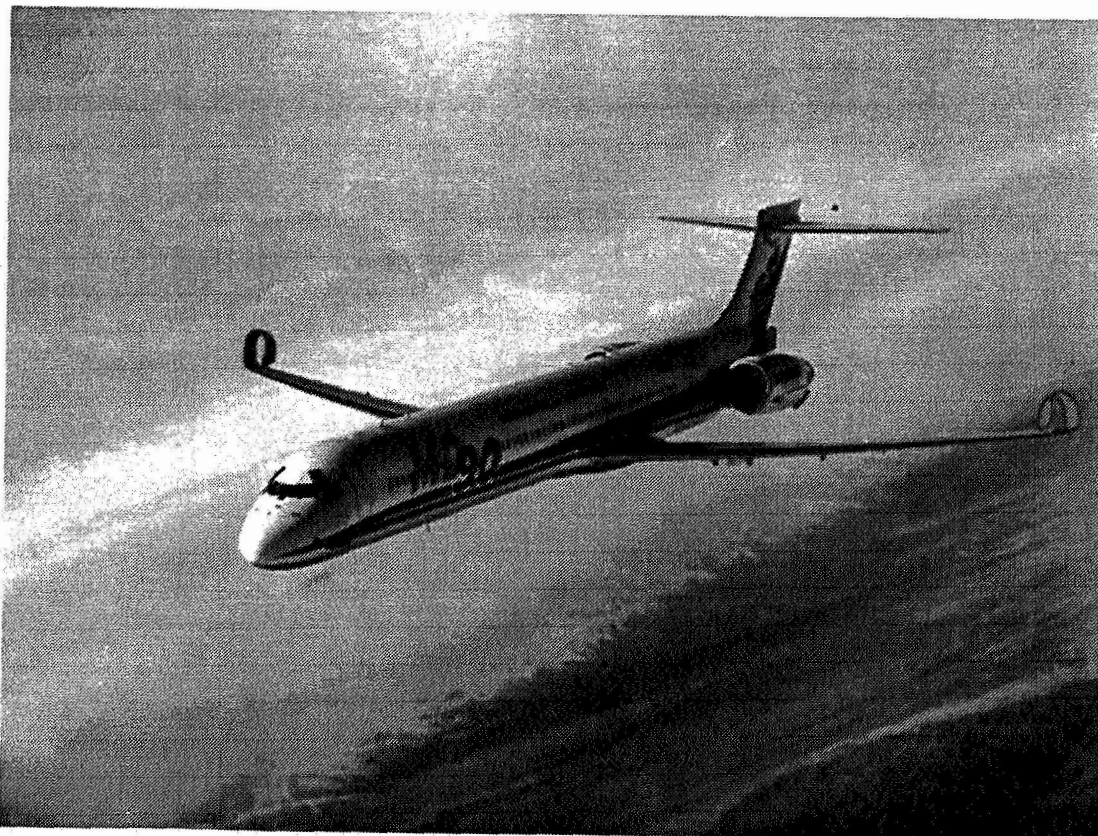
The Lockheed box-plane, shown below, achieves even greater drag reduction at a given span and height than the circular ring wing (in fact the theoretical minimum vortex drag) in a configuration with reasonable high-speed performance (note the desirable transonic area-ruling) and some structural advantages. Fuel volume, landing gear integration, $C_{L_{\max}}$ penalties, and lower section Reynolds numbers are some of the disadvantages for this concept.



SPEED	0.95
PAYLOAD	84,800 LB
RANGE	5500 NM
OPERATING WT	281,392 LB
GROSS WT	664,896 LB

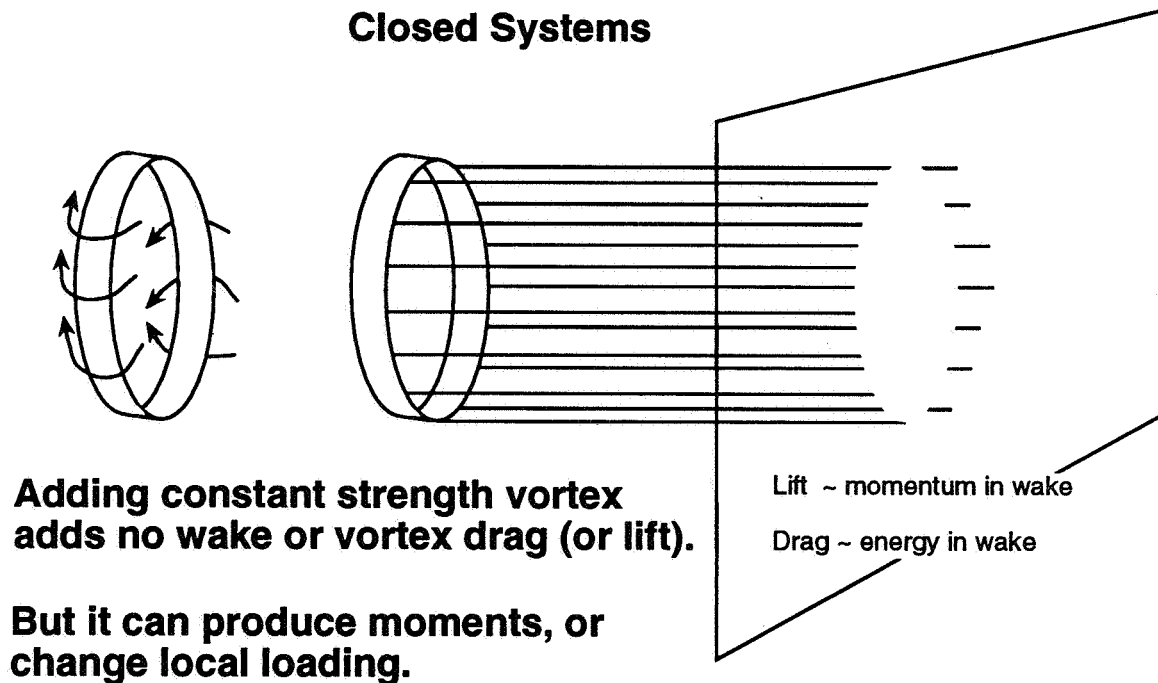
Examples: Closed Systems

The recently-patented “spiroid wing tip” produces a reduction in induced drag, much like that of a winglet. However, its closed planform shape may make it possible to reduce local lift coefficients—often a problem for winglets.



Closed Systems: How they Work

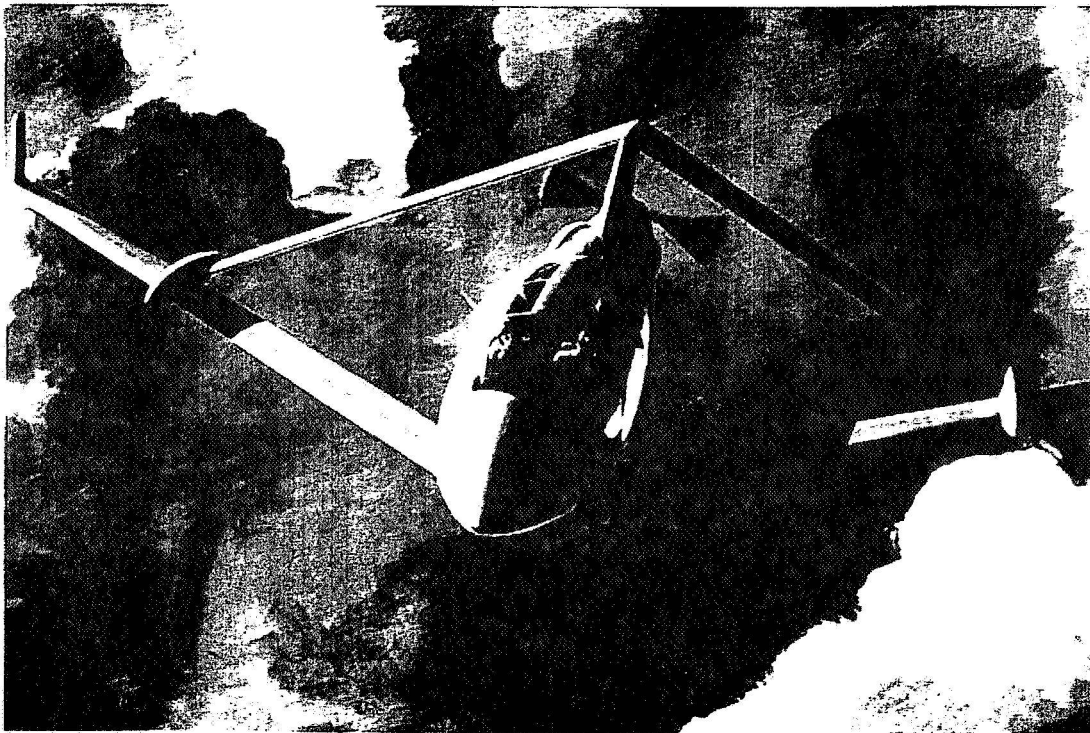
Although a closed lifting system may eliminate the wing tips, it does not eliminate the trailing vortex wake. In fact, the lift produced by the system can be directly related to the velocities in the wake that lead to induced drag. These systems are still interesting because one may add a constant circulation vortex ring to the system without changing the wake. Such a constant strength vortex distribution does not add any lift, but it may be used to produce moments without induced drag penalties or to manipulate section lift coefficients in a desirable way.



Examples: Strutted-Wings

Aircraft concepts that employ auxiliary aerodynamic surfaces as struts to improve both aerodynamic and structural efficiency have been studied extensively.

- In joined-wing designs (below) the horizontal tail sweeps forward and joins the main wing, forming a strut. The tail is then in compression, reducing wing bending moments. If the tail is large enough to be positively loaded, some induced drag savings is achieved, while if it is carrying a down-load, the closed loop feature of the system minimizes trim drag. The concept was studied by Boeing as a radar platform and by others as a commercial transport.
- Pfenninger's laminar designs with lifting struts exploit the nonplanar strut geometry primarily for structural weight and stiffness, although some induced drag reduction may be achieved.



4-PLACE GENERAL AVIATION AIRPLANE

Examples: Winglets

The most common contemporary nonplanar wing configuration is the wing with winglets, as seen below on the McDonnell-Douglas MD-11. These surfaces do reduce induced drag for a given span, as well as providing a means of quickly distinguishing the airplane from a DC-10. The MD-11 design includes small downward winglets, while the 747-400 employs a full-chord single winglet, and many other variations are possible.

A variant of the winglet concept, the C-wing is discussed later in this paper. It involves adding a horizontal winglet extension (a wingletlet?) and has interesting aerodynamic, structural, and control implications.



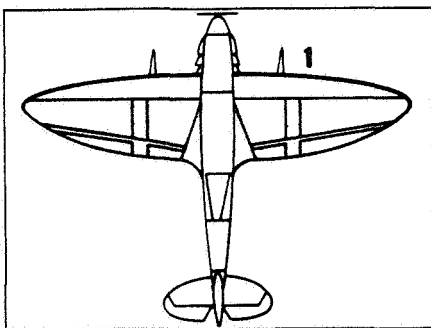
Examples: Nonplanar Wakes

The induced drag of a nonplanar system can be lower than that of a planar system of the same lift and span. This is true even when the wing surfaces themselves are coplanar, but their vortex wakes are not. Examples of this phenomena include:

- America's Cup sailboat keels. Here the keel and rudder (or twin keel surfaces) are coplanar, but due to the substantial leeway angle and longitudinal displacement of the two surfaces, the wake downstream of the boat resembles that of a biplane system and the induced drag is reduced substantially.
- Crescent wings. This phenomenon was postulated as the reason for the distinctive planform shape of some bird wings and fish fins, although the effect is almost unmeasurable.
- Split-Tips. This design was created to exploit the nonplanar wake geometry and is discussed in more detail in a subsequent section of this paper.

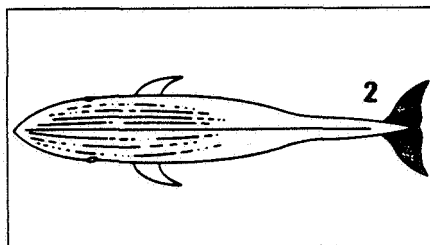
Nature had crescent-shaped wings in mind

How to fly like a fish

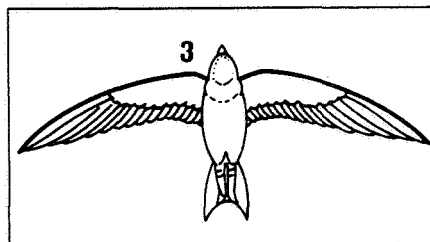


A Spitfire's wing is roughly elliptical ...

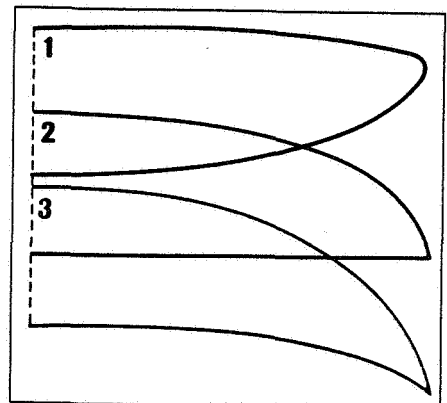
■ Engineers have discovered a trick of aerodynamics that birds, fish and whales have known for eons—and as a result, airplane wings, whose basic shape has remained unchanged for half a century, may take on a radical new look.



a whale's tail flares back at the tips ...



and the swift's wing is crescent-shaped

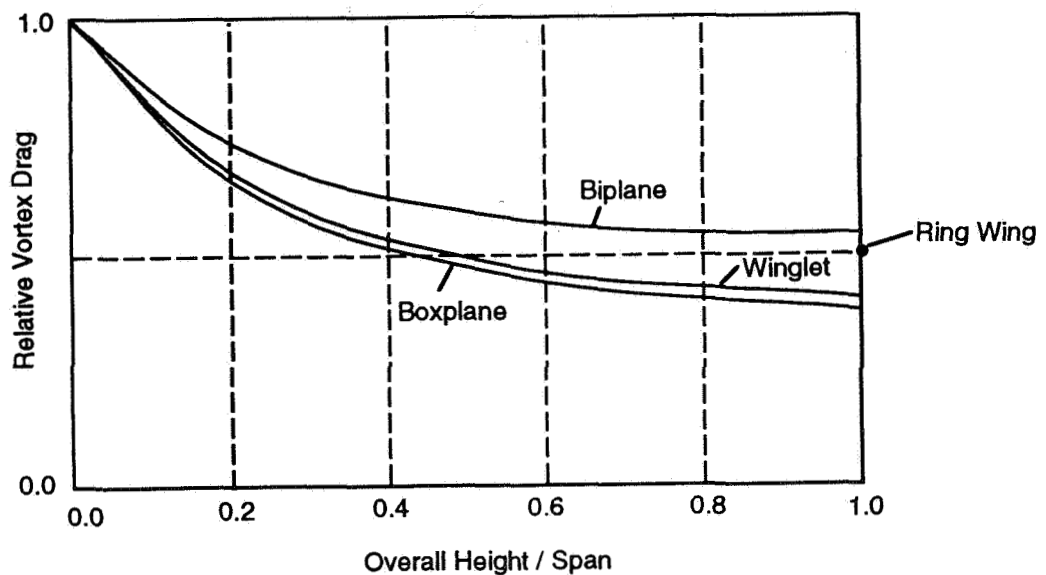


Three designs: (1) Classic elliptical wing; (2) the whale's tail with curved leading edge; (3) the swift's crescent with back-curved leading and trailing edges

What is Possible?

Each of these configurations provides particular advantages and disadvantages, although each benefits from some reduction in induced drag compared with the conventional monoplane. The reduction in vortex drag is shown below for biplanes, boxplanes, and winglets with varying ratios of height to span. These results were computed using an optimizing vortex lattice code, but agree with classical solutions from Prandtl, von Karman and Burgers, Cone, and Jones. Note that the boxplane achieves the lowest drag for a given span and height, although winglets are quite similar. Considerable savings in induced drag are possible for a fixed span if large vertical extents are permitted.

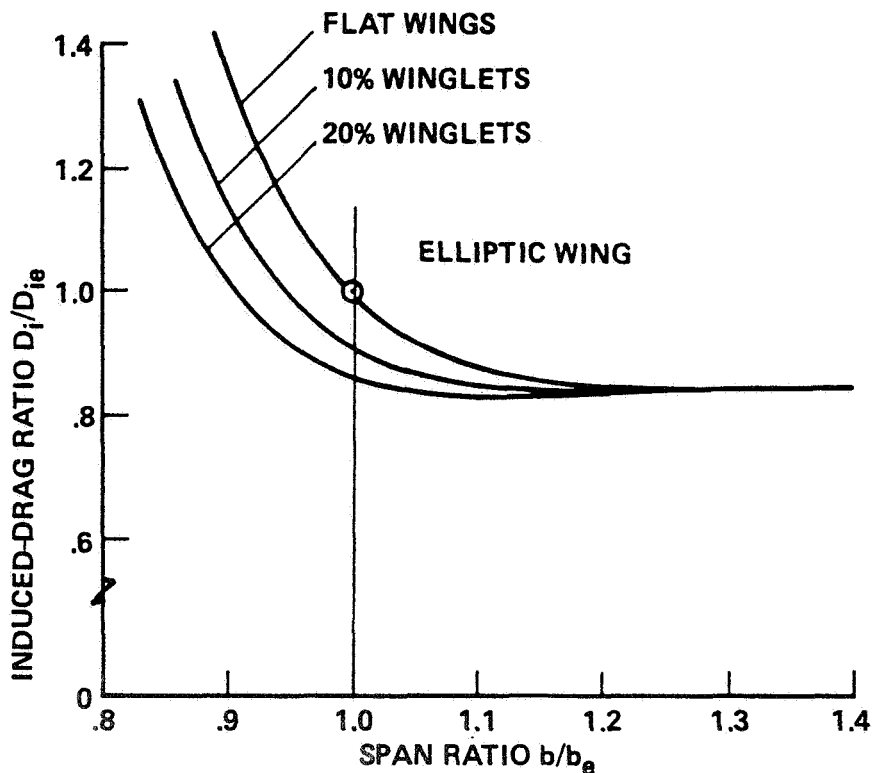
What is Possible?



What is Possible?

Of course, adding vertical surfaces such as winglets add wetted area and weight due to higher bending moments, while the weight of a cantilevered biplane is increased since for a fixed total area, the chords (and dimensional thickness) of each wing are halved. Jones showed that with fixed integrated bending moment (a rough indicator of wing weight) winglets produced about as much drag savings as planar tip extensions. More recent analyses using more realistic weight estimation methods have yielded similar results (but with much a less broad optimum).

For some applications, this discouraging result is not relevant since the aircraft must operate with a span constraint, or because the structural arrangement is not simply analyzed.



Induced drag of wings having the same bending moment at the wing root.

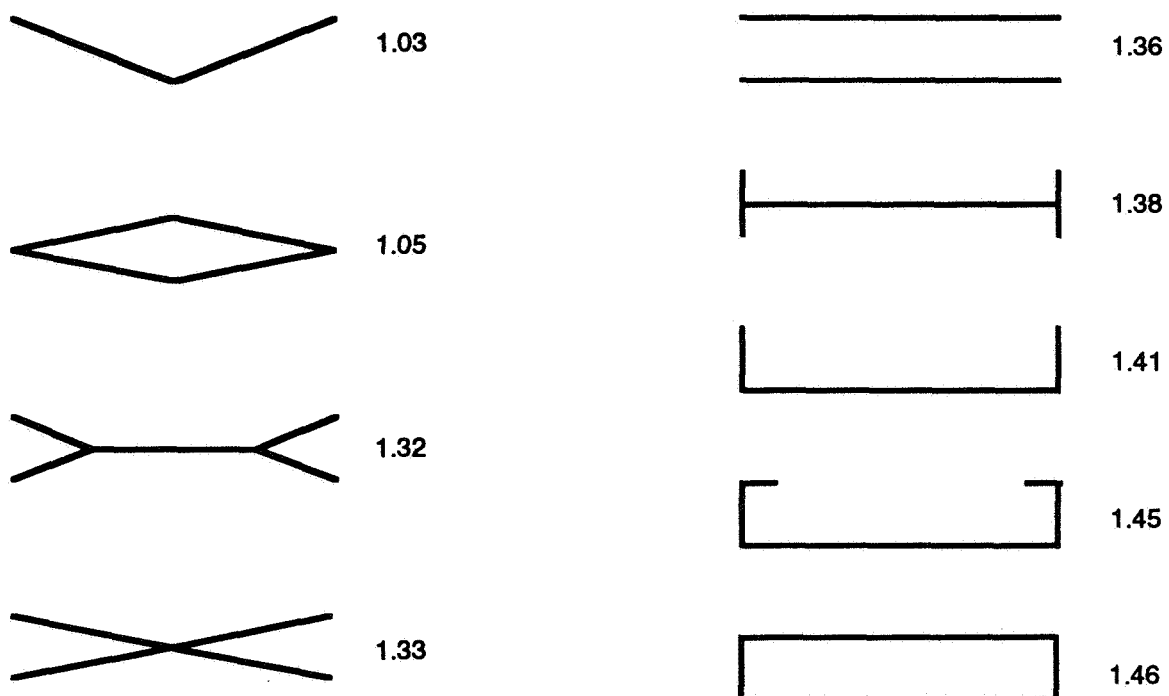
What is Possible?

The figure below illustrates the effect of nonplanar wing shape on span efficiency. Each of the geometries, shown in front view below, is permitted a vertical extent of 20% of the wing span. Each design has the same projected span and total lift. The results were generated by specifying the geometry of the trailing vortex wake and solving for the circulation distribution with minimum drag. So, each of the designs is assumed to be optimally twisted. This was done by discretizing the vortex wake and solving a linear system of equations for minimum drag with a constraint on overall lift. Similar results for a variety of shapes have been described by Cone, Munk, Letcher, Jones, and others.

The results illustrate the variability in span efficiency among these designs. Note the relatively small gain for the diamond-shaped device and the wing with dihedral, while the C-wing shape achieves essentially the same drag as the boxplane.

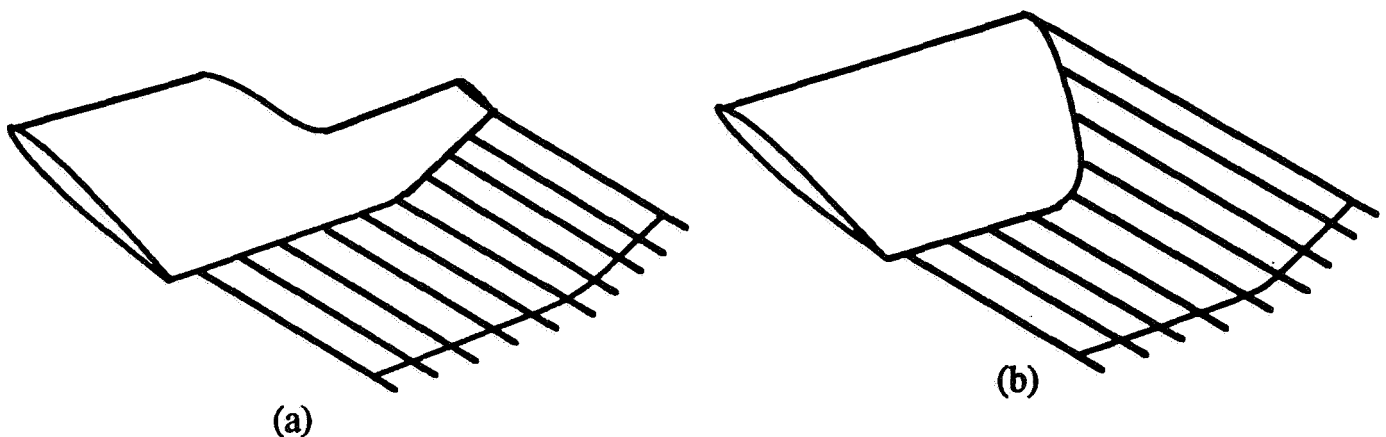
Span Efficiency of Various Nonplanar Shapes

Height / Span = 0.2



Nonplanar Wakes: The Split Tip

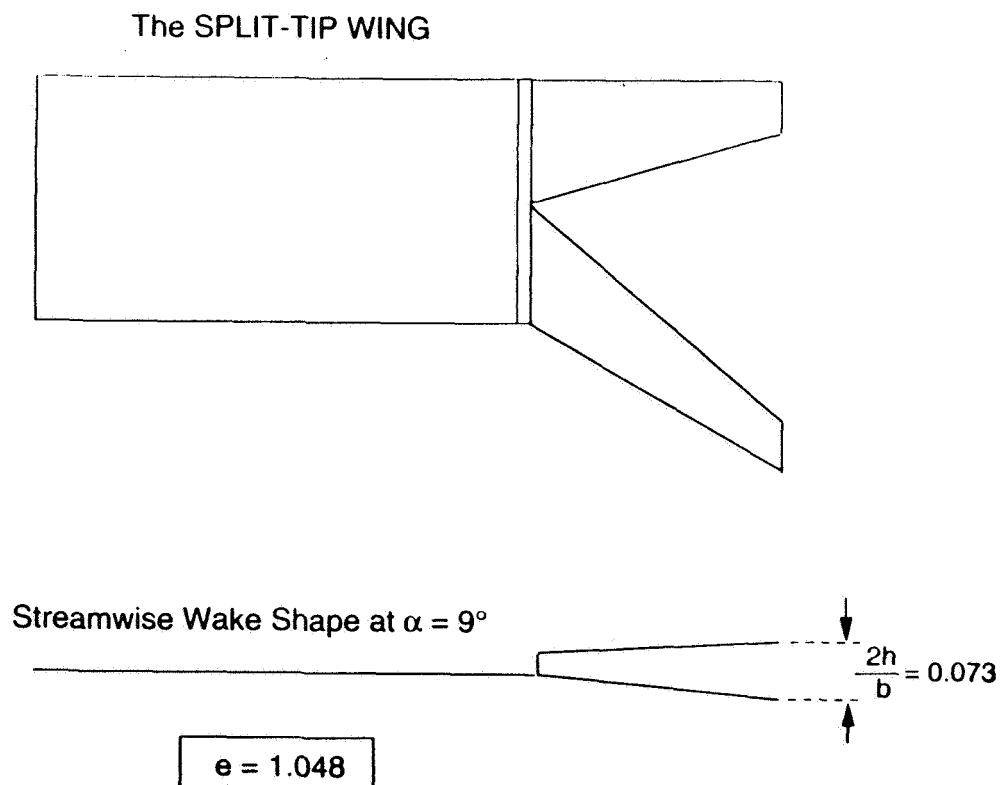
From among this list of possible designs, we choose two ideas to look at in a bit more detail. The first concept is based on the notion that it is the shape of the wake, not the shape of the wing that is important to the total vortex drag. By sweeping the trailing edge of the wing sharply backward or forward and placing the wing at an angle of attack, one may generate a wake shape that looks very much like the wake of a wing / winglet combination. The difficulty here is that we must twist the wing or create a planform shape that achieves the optimal load distribution that corresponds to this geometry. Moreover, for reasonable wing planforms, the amount of out-of-plane wake deformation is very limited. For this reason the potential gains associated with crescent-shaped wings or wings with highly forward-swept trailing edges are very small ($\sim 1\%$ or less) unless the wing has a very low aspect ratio.



Nonplanar Wakes Shed from Wing with Winglet (a), and Planar Wing (b).

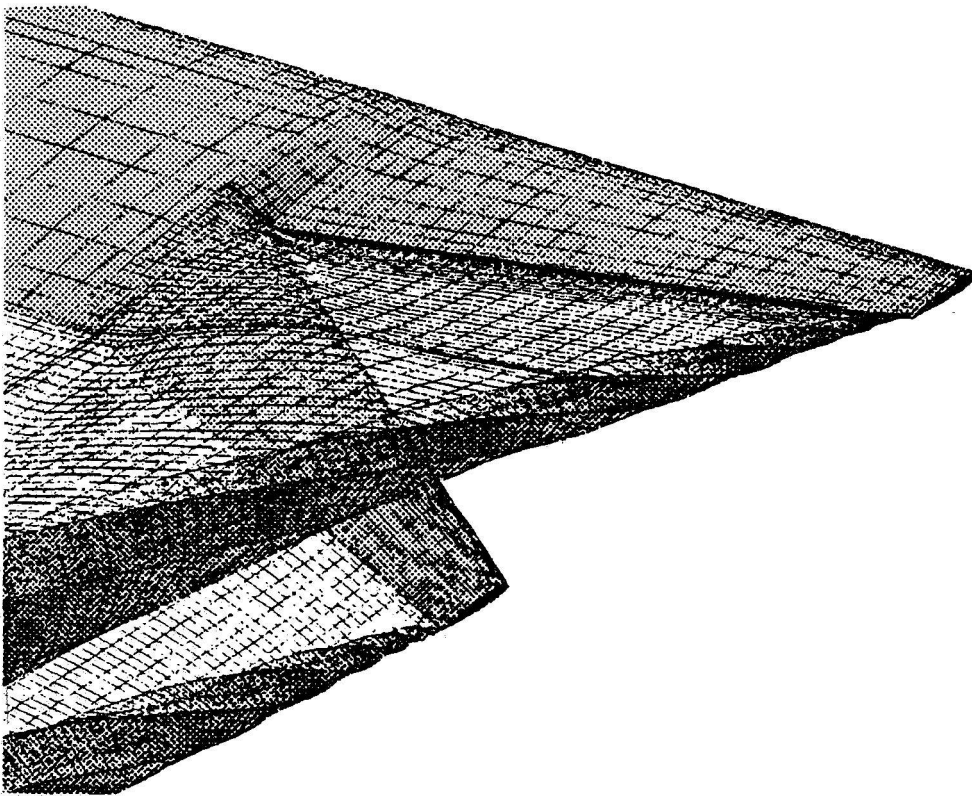
Nonplanar Wakes: The Split Tip

To exaggerate this effect, a wing with the geometry shown below was created. The idea here was to generate a shape whose potential span efficiency gain for a given amount of out-of-plane deformation was large. Based on the previous figure, a split tip geometry for the wake was selected as a shape that could be generated by wake deflection and the wing planform shown below was investigated. The figure shows the planform shape and the shape of the wake trace when the wing is at 9 degrees incidence. Based on this wake shape, an induced drag savings of about 5% is possible when the wing is optimally loaded, and more as the angle of attack is increased.



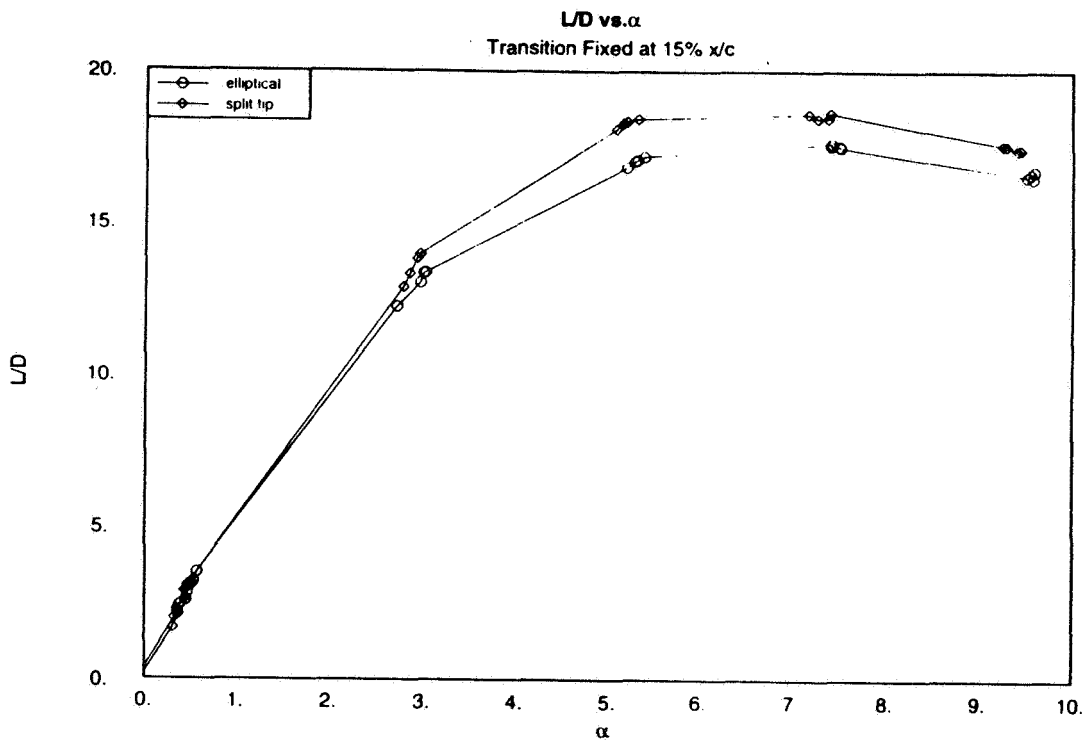
Nonplanar Wakes: The Split Tip

Of course, the wake does not trail from the wing in the streamwise direction and careful computation of rolled-up wake geometry and inviscid drag shows that the effect of wake-rollup is to roughly double the gain expected for a streamwise wake. The 11% increment in span efficiency was significant and the concept was studied in more detail both theoretically and experimentally. The figure below shows the computed wake geometry and wing paneling used to compute vortex drag with the high-order panel code A502.



Nonplanar Wakes: The Split Tip

Two wings were constructed and tested at NASA's Ames Research Center. The first was an untwisted planform with an elliptical chord distribution, unswept quarter chord line, and an NACA 0012 airfoil section. The second wing of the same area and span, also untwisted with a 0012 airfoil section, incorporated the split tip geometry. Both models were designed to incorporate a sensitive internal balance so as to minimize support interference. The figure below shows the ratio of lift to drag for each of these wings confirming the predicted lower drag of the split tip geometry.



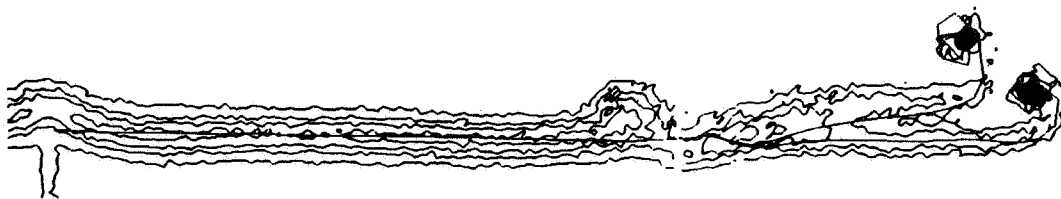
Nonplanar Wakes: The Split Tip

To further confirm the theoretical predictions, estimates of vortex drag and wake shape were compared from calculations, balance data, and a detailed wake survey. From the wake survey, an explicit estimate for the vortex drag can be obtained. This value agrees well with the computed result and the balance data.

The results are intriguing, and although the configuration was selected to exaggerate a particular effect rather than to serve as a good airplane wing, its application to aircraft, propellers, and rotors is currently under investigation.

The effect is significant, but not large and we next consider a design with more substantial implications for aircraft design.

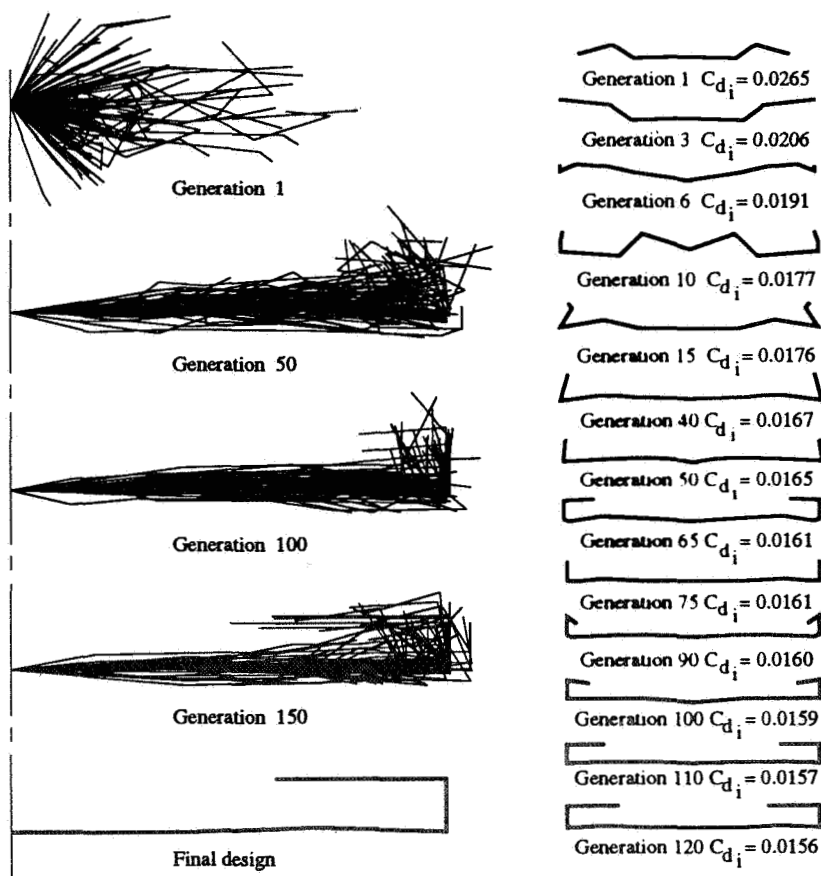
TOTAL PRESSURE CONTOURS from WAKE SURVEY
COMPARED WITH
COMPUTED FORCE-FREE WAKE SHAPE



Span Efficiency	Computed	$C_D - C_{Dp}$	Survey
Elliptical Wing	0.970	0.98	0.972
Split Tip	1.113	1.10	1.096

The C-Wing: A Novel Nonplanar Wing Configuration

From the survey of nonplanar wing geometries discussed previously, one is struck by the fact that one need not produce a closed system such as the box plane to achieve essentially all of the induced drag savings that this configuration offers. In particular, extending the upper part of the box only 10% of the span inward from the tip achieves a span efficiency within about 1% of the complete box. Thus, one could achieve the drag savings of the box plane without the Reynolds number and fuel volume penalties of the two-wing design. Furthermore, the small horizontal tip extensions have some interesting implications for airplane design. This configuration was independently “discovered” by a genetic algorithm that was asked to find a wing of fixed lift, span, and height with minimum drag. The system was allowed to build wings of many individual elements with arbitrary dihedral and optimal twist distributions. The figure below depicts front views of the population of candidate designs as the system evolves. On the right, the best individual from a given generation is shown.



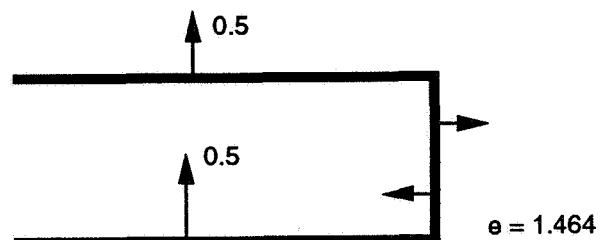
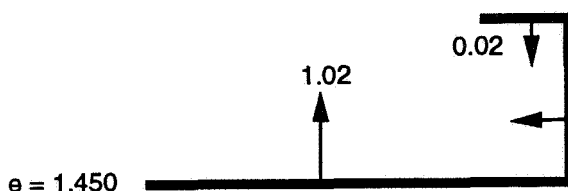
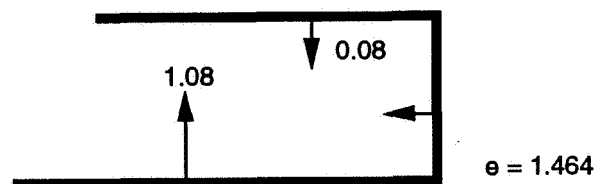
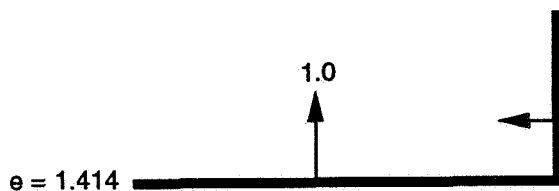
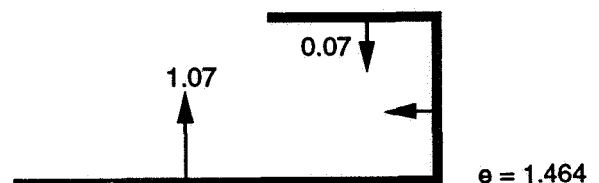
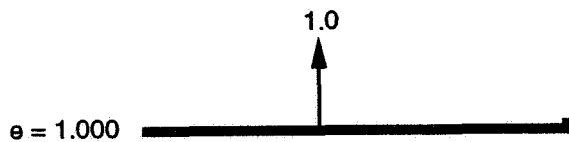
C-Wing Configuration

The optimal loading of this lifting system is shown in the figure below. The circulation of the main wing is carried onto the winglet so that the winglet is loaded inward. When the horizontal extension is added to the winglet, forming the "C" shape, the circulation is extended from the winglet as well, producing a surface that is loaded downward for minimum induced drag at fixed total lift. It is only when the lifting surface is extended to the centerline to form a box plane that the upper wing can efficiently carry an upload. This is because, as mentioned previously in connection with closed systems, we can superimpose a constant circulation ring on the closed system to redistribute the lift without changing the wake.

This download on the C-wing horizontal surfaces affects structural weight and trim and the implications for aircraft configuration concepts was intriguing.

Geometries Analyzed

All with fixed span, area, and total lift



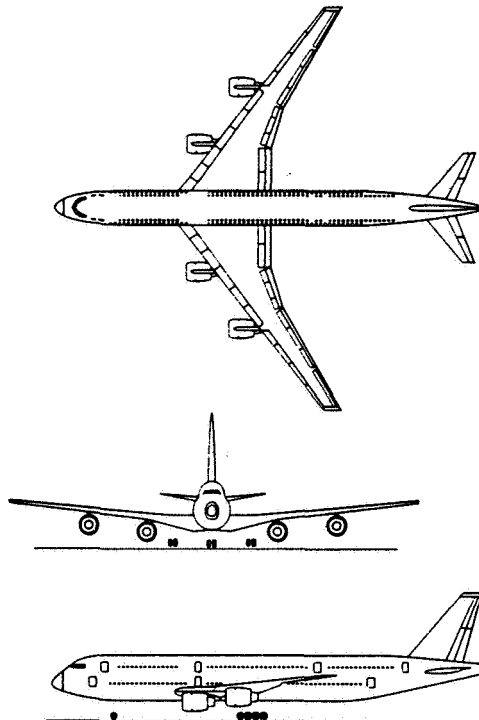
C-Wing: Application to Large Aircraft

The first application of this concept to an aircraft design study was in connection with recent interest in very large civil transports. Many of the issues listed in the figure below are problematic for the conventional configuration. Airport and manufacturing constraints limit the span of a new large aircraft. The location of the outboard engine is a problem, and the height of the vertical tail becomes excessive.

LARGE AIRCRAFT ISSUES

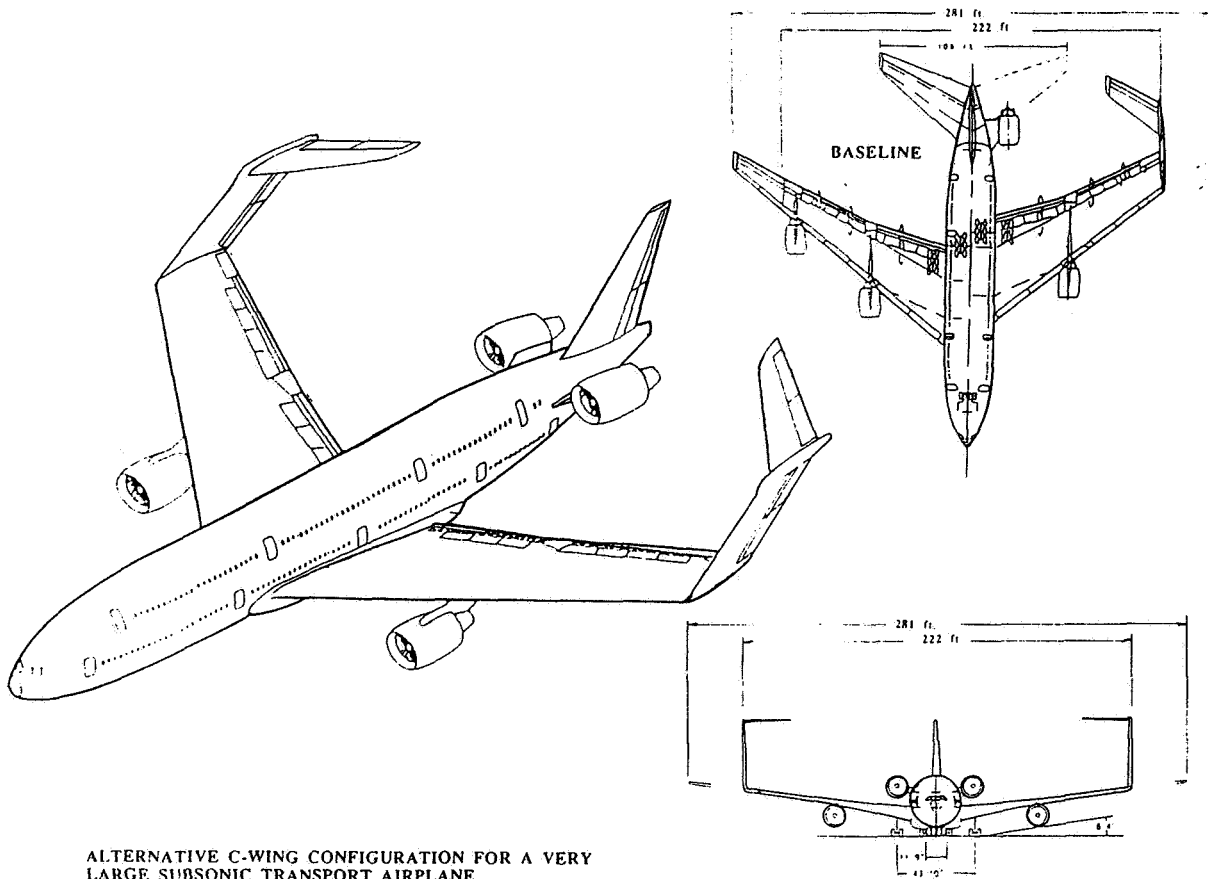
Problem:

- Runway limits
- Taxiway limits
- Gate limits
- Emergency evacuation
- Community noise
- Wake vortices
- Structural limits



C-Wing: Application to Large Aircraft

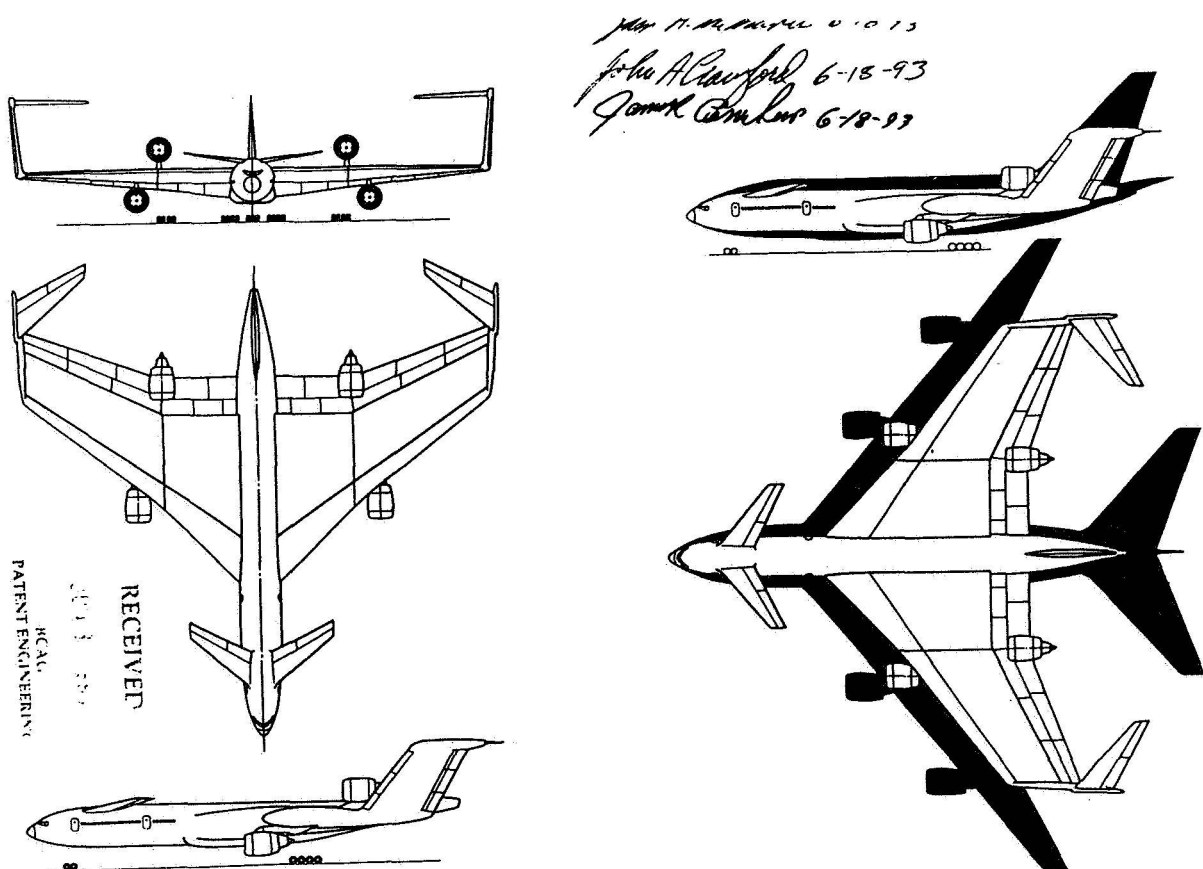
Using the C-Wing configuration, the span of an otherwise conventional large aircraft can be reduced. Because the fuselage tends to be rather short on double deck configurations, the horizontal tail location is not much farther aft than the wing tips making it possible to consider using the C-wing as the primary pitch control surfaces. (The horizontal C-wing surfaces provide more stability for a given area as they are not affected by the aft fuselage flow field and are less affected by wing downwash. Moreover, they provide a positive trimming moment when optimally loaded.) The removal of the horizontal tail makes the use of aft-fuselage-mounted engines a possibility, eliminating some of the severe problems with the original outboard engine location. Despite some attractive features, however, the performance advantages for this configuration are not substantial, and probably not worth the risk associated with the unconventional design.



C-Wing: Application to Large Aircraft

As the number of passengers reaches 600-800, the possibility of including some passenger cabin area inside the wing appears more attractive. For the C-Wing configuration the wing span is reduced and the wing chord increased to maintain the desired lifting area and structural support for the tip surfaces, making this idea even more appealing. Furthermore, when a long empennage is no longer required for horizontal and vertical tail surfaces, one is led to the rather unconventional large aircraft configuration pictured below.

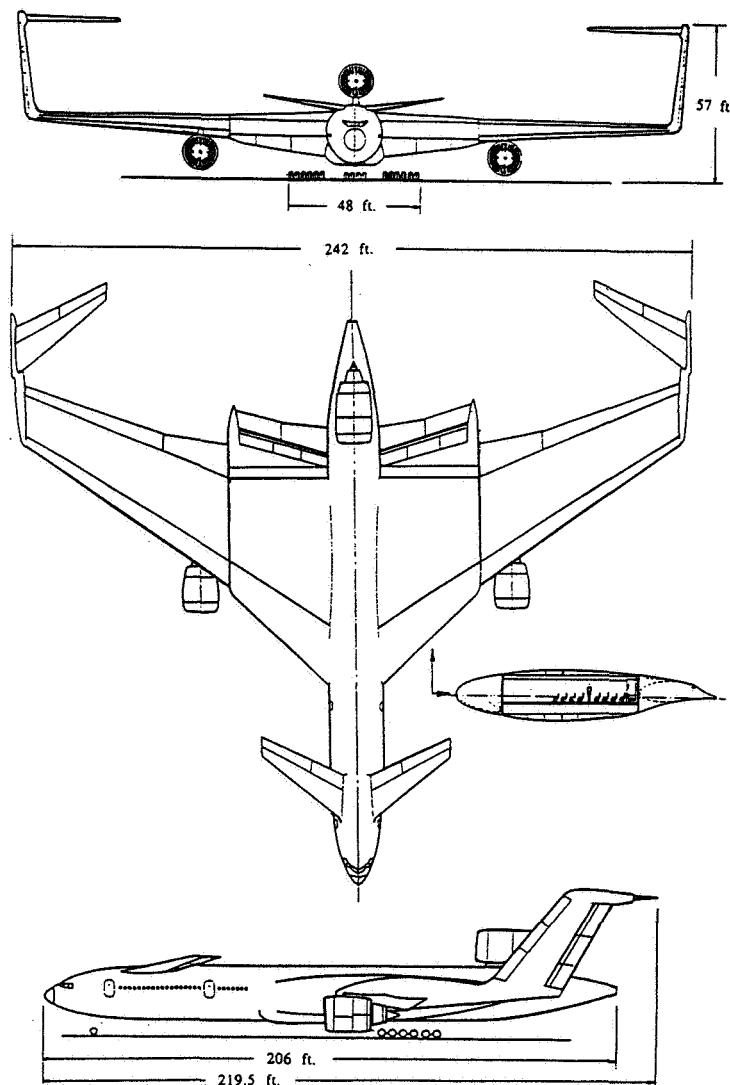
This design comprises a three-surface configuration providing a large allowable c.g. range, with a relatively lightly loaded wing to simplify high-lift system requirements and accommodate passenger cabins in the wing. The vertical and horizontal tip extensions provide an efficient means of satisfying stability and control constraints.



C-Wing: Application to Large Aircraft

As the design evolved to the tri-jet shown below, the wing span was increased, but remained substantially lower than the conventional design. More efficient use was made of the existing 777 fuselage area and the thick inner wing section was modified based on an investigation of high-speed thick sections.

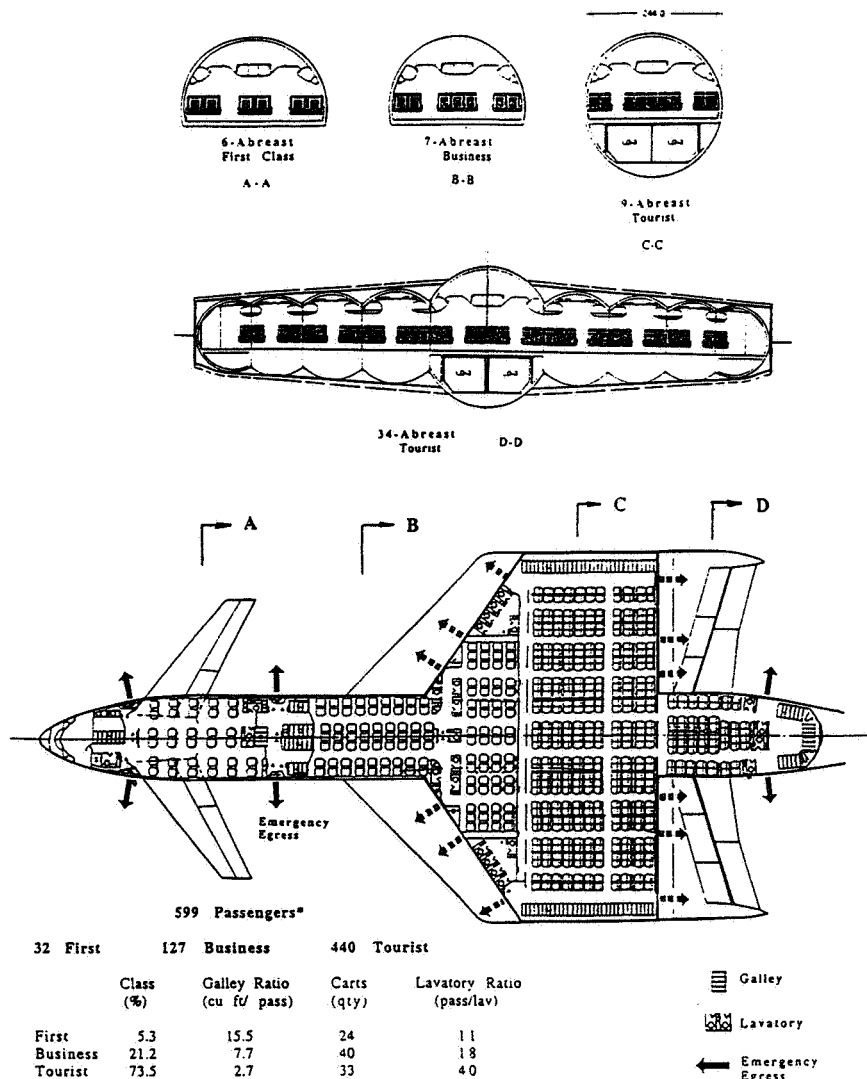
The basic idea in this conceptual design study was not to obtain the highest performance for this large aircraft, but rather to provide a feasible solution to the large aircraft problem. The design addresses many of the problems that arise from the simple scaling-up of the conventional design.



C-Wing: Application to Large Aircraft

The layout of passengers and accommodations (LOPA) for this aircraft is shown below.

By including passenger cabins in the inner wing area, it is possible to accommodate all 600+ passengers (tri-class) in a single deck arrangement. This resolves many of the difficult loading and emergency egress issues associated with double deck cabins. The use of the cylindrical fuselage section of a Boeing 777 keeps most of the passengers near the centerline, provides windows for many, and permits some growth by conventional fuselage stretching.



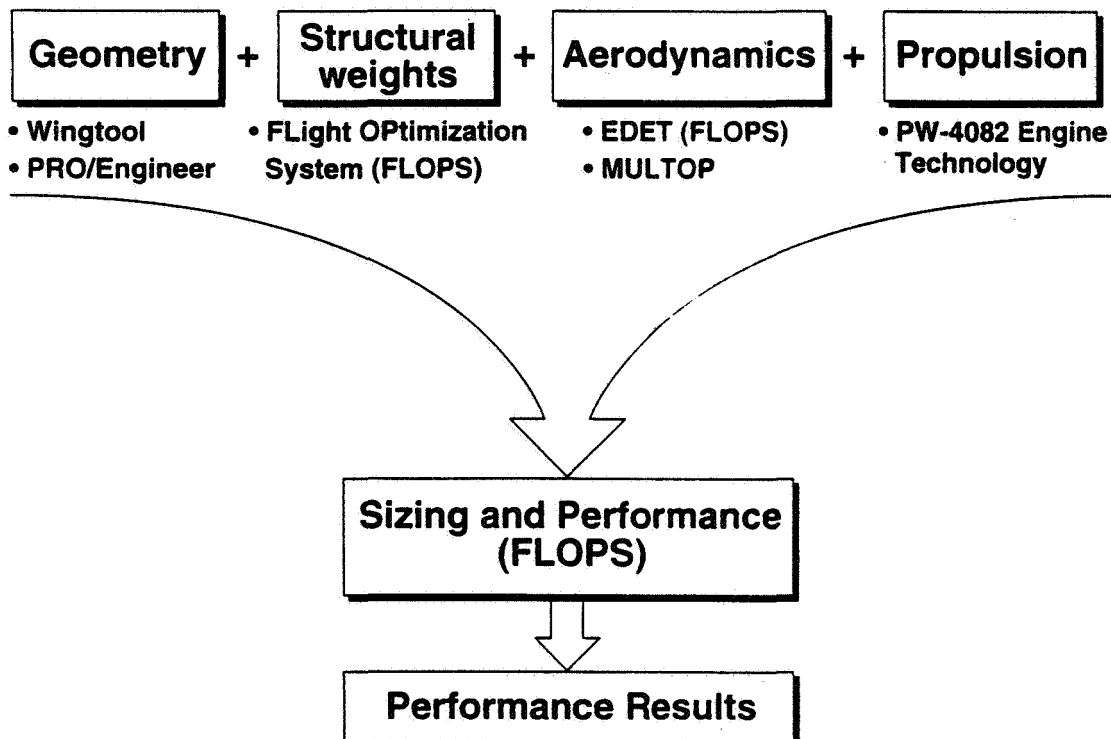
[*Approximately 750 passengers in an All Tourist configuration.]

C-Wing: Application to Large Aircraft

Studies at Stanford and Boeing were undertaken as part of NASA's Advanced Concepts Program in 1995. Concurrently, initial sizing and optimization of the original concept were pursued at NASA's Langley Research Center.

Each of these studies involved analysis and numerical optimization of the basic concept. At Langley the FLOPS computer program was modified to handle this geometry. At Stanford and Boeing, the PASS and ACSYNT codes were also modified to analyze this design. Existing engine decks representative of modern high bypass ratio engines were used rather than estimating the performance of future technology. This represents a rather conservative approach. Additional analysis with ADP engines and laminar flow control remains to be completed, but several aspects of the design suggest that gains from such technologies may exceed those obtained with conventional designs.

DESIGN AND ANALYSIS METHOD



C-Wing: Optimization

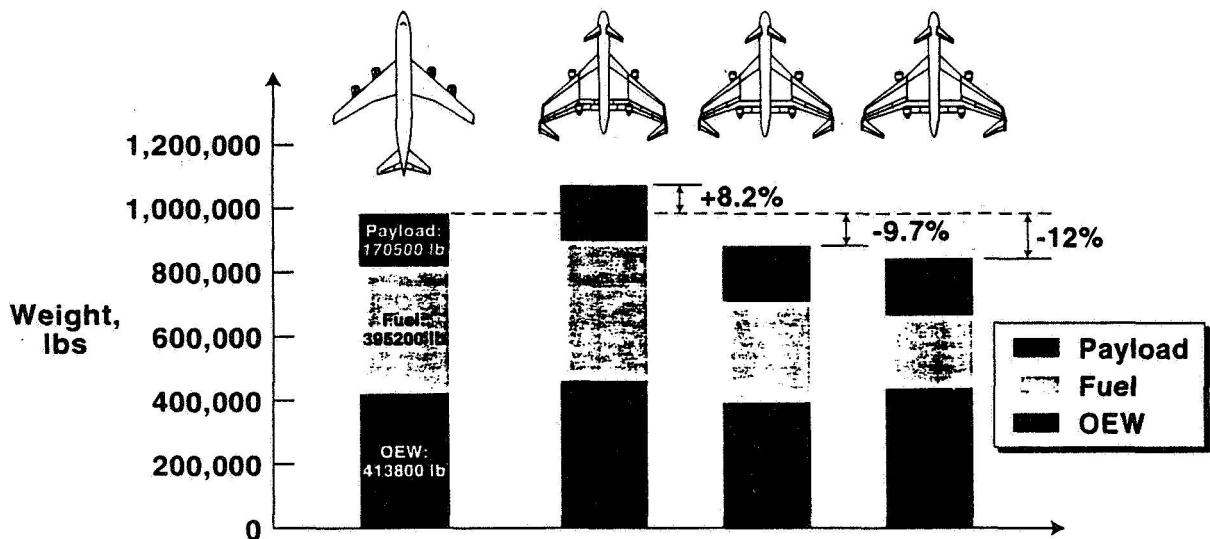
The figure below illustrates example results from one of these studies with the following assumptions:

Design Mission and Constraints

Parameter	Langley	Boeing/Stanford
Range	7000 nmi	7000 nmi
Mach	0.85	0.82
Passengers	800	600 (tri-class)
Field Lengths	12000	11000
# Engines	4	3
Approach	150 kts	

Other constraints typical of FAR Part 25.

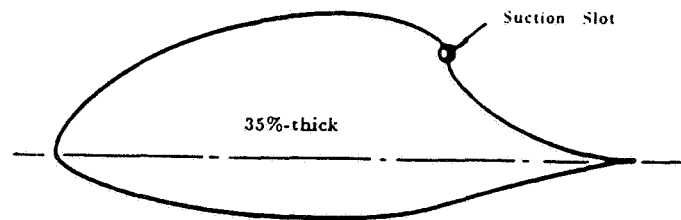
The results indicate that substantial reductions in take-off weight are possible, even though the concept was aimed primarily at resolving some of the problems associated with very large aircraft rather than providing much better performance.



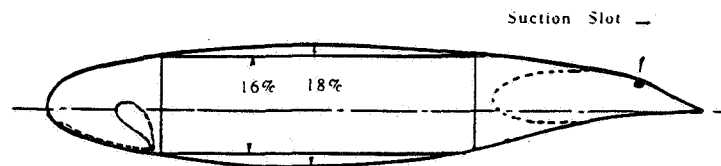
Model	Conventional Baseline	C-Wing 1	C-Wing 2	C-Wing 3
Material	Composite	Composite	Composite	Composite
AR	8.42	4.07	6	6
Wing area, ft	8136	15116	11052	12514
Thrust/Engine, lb	52509	74399	46691	45251
Span, ft	229	236	245	260
Goldschmied factor	-	1.0	1.0	2.0
TOGW	979500	1060200	884900	861500

C-Wing: Application to Large Aircraft

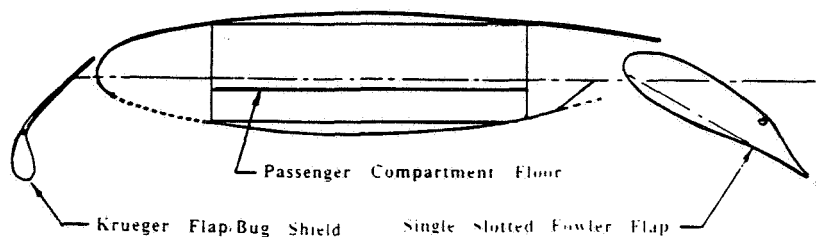
The results suggested that, at least with the original LOPA concept, the design improved with very thick sections inboard. In conjunction with related studies at M.I.T., Purdue, and the University of Illinois, a set of airfoils well-adapted to the inboard wing sections of this concept were developed and their performance was modeled in the aircraft sizing studies. These sections utilized suction on the aft area of the section to extend the region of high thickness aft and to reduce superelevations over the upper surface. Some ideas for the integration of these sections with the passenger compartment and high lift system are illustrated below.



(a) Classic Very Thick Subsonic Griffith Airfoil



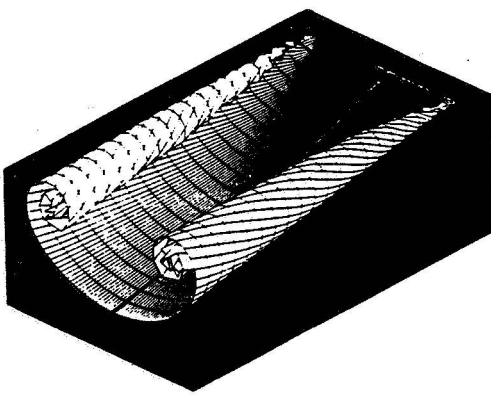
(b) Possible 18% Transonic Griffith Airfoil



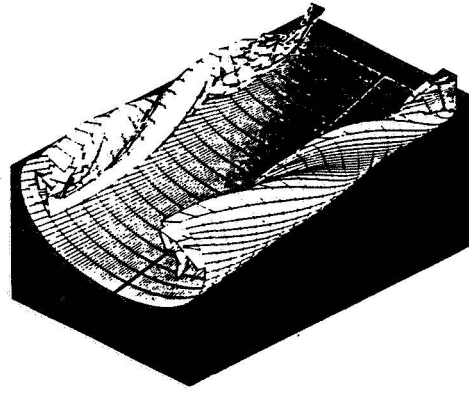
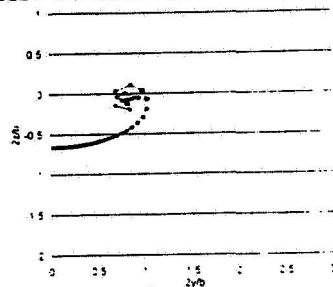
(c) High-Lift System Concept for a Transonic Griffith Airfoil

C-Wing: Application to Large Aircraft

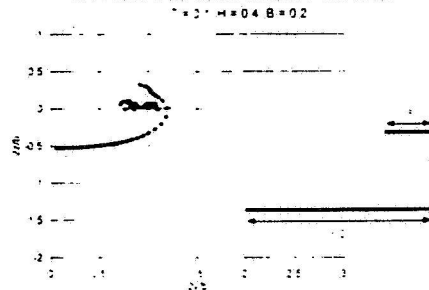
One of the possible advantages of the C-Wing concept involves the development of the trailing vortex wake system from this geometry. A major concern with large aircraft is the hazard of the trailing vortex wake to other aircraft. The C-wing distributes the vorticity in the wake over a longer distance, reducing the intensity of the wake sheet, but the vortices shed from the wing tips and the tips of the C-Wing extensions are closer together than they would be for a conventional design, accelerating the breakdown of the wake system. Preliminary studies of this phenomena were undertaken at Tuskegee University and are not complete, but do illustrate some of the differences between the wake of the C-Wing and that of a conventional design.



ELLIPTIC WING VORTEX SHEET ROLLUP



CWING VORTEX SHEET ROLLUP

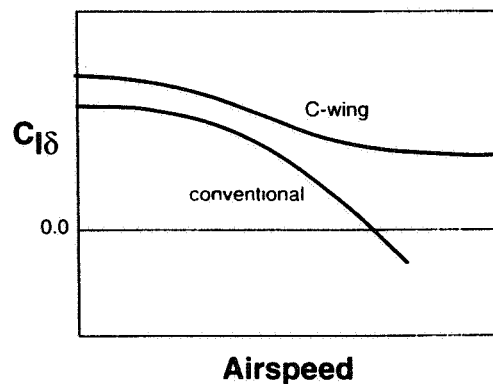
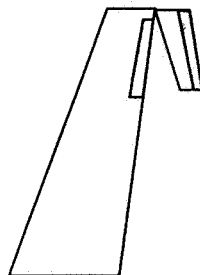


C-Wing: Application to Large Aircraft

A significant concern for this type of configuration is its aeroelastic stability characteristics. The swept C-wing design might be expected to lower the torsional frequencies of the system and permitting additional coupling between primary bending and torsion modes. The lifting surfaces near the tips do introduce substantial damping to the torsion modes so that the flutter characteristics of this design are not obvious. One of the attractive features of the C-Wing geometry, however, is that even if the uncontrolled flutter modes are less stable than a conventional wing, the system is more controllable. With control surfaces on the main wing and the horizontal tip extension, one may independently control lift and torsion. This makes the system more easily controlled than a conventional wing in which deflection of an aileron introduces both torsion and bending perturbations. The figure below shows how this concept may be used to eliminate aileron reversal for the C-wing design.

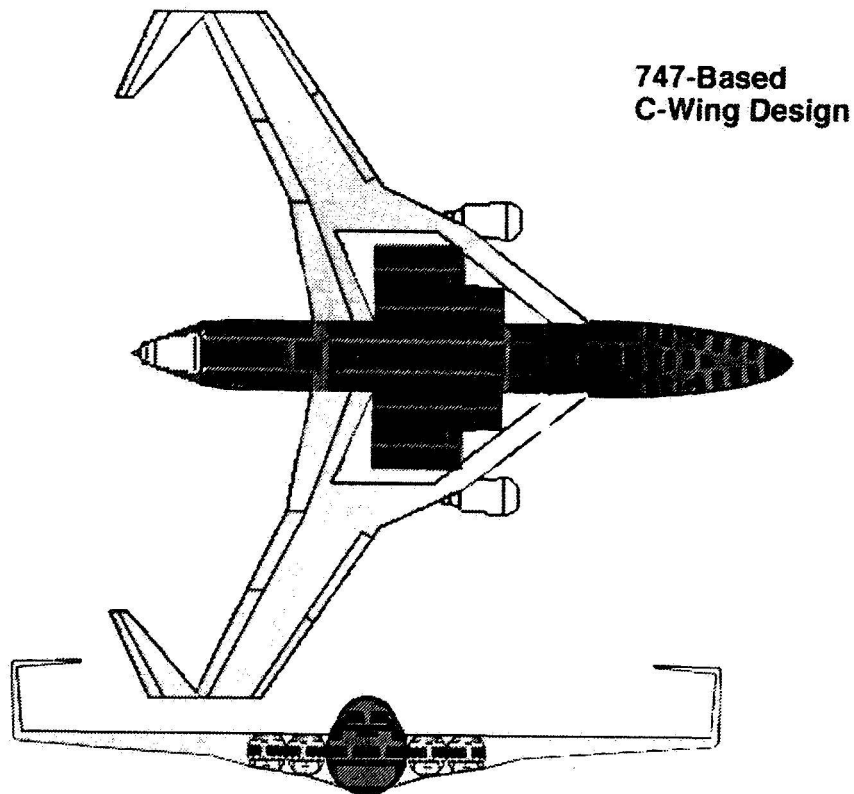
C-Wing Aeroelastic Features

**Independent control over lift / torsion prevents
aileron reversal, increases control of flutter modes**



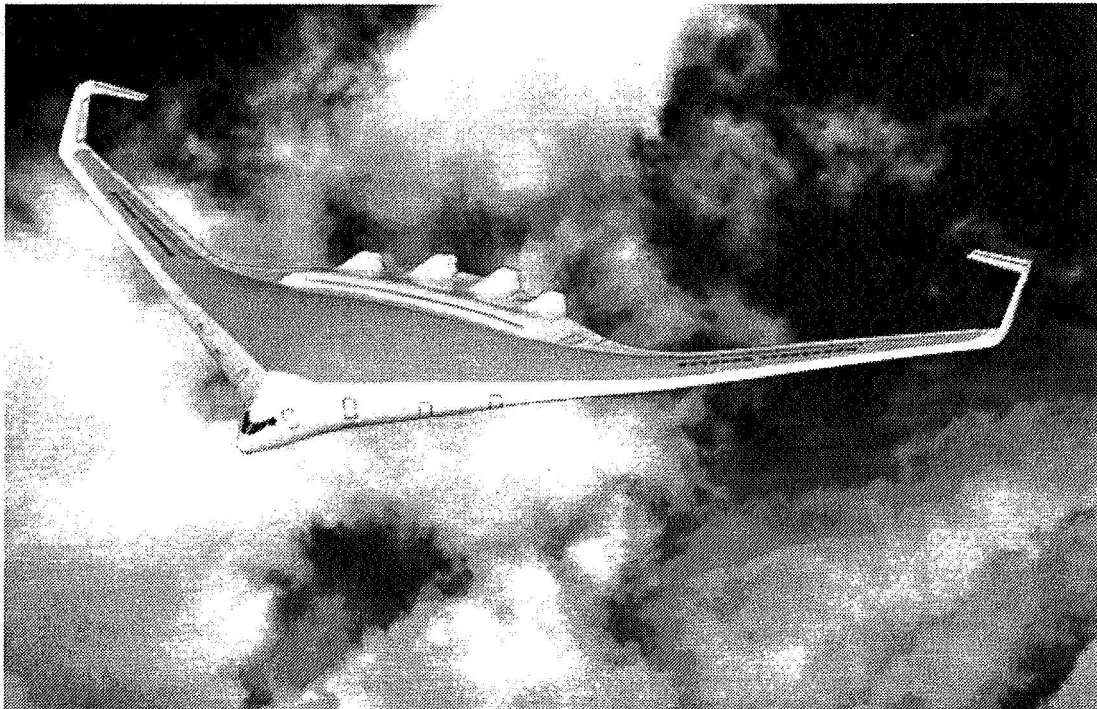
C-Wing: Application to Large Aircraft

A second round of conceptual design iteration remains to be completed, however, designs such as that shown below are under investigation. In this design, the planform is modified slightly to permit larger root t/c's. A 747-based fuselage is used to accommodate more of the payload in a conventional environment (more windows, conventional egress) and reduce the passenger lateral extent. These two changes may make conventional airfoil sections (without boundary layer control) more attractive. By removing the canard from the design, efficient trim is still possible without active controls.



C-Wing: Application to Large Aircraft

The figure below shows the addition of C-Wing tips to the McDonnell-Douglas Blended Wing Body concept. The addition of these surfaces would permit the BWB configuration as currently envisioned to fly with positive static stability with no change to the aerodynamic design of the highly-loaded, thick transonic wing. The added weight and skin friction drag of these surfaces may be partly offset by a reduction in induced drag and by the relaxed moment constraints on the main wing sections. Although the concept remains to be studied in any detail, its implications for controllability and efficient trim of this flying wing design are promising.



C-Wing Summary

The advantages of the C-wing configuration for a large capacity subsonic transport are listed below. They include those directly associated with the nonplanar wing geometry and those that arise indirectly from the overall configuration shown on previous pages.

Nonplanar Wing:

1. Reduced span or reduced vortex drag at fixed span
2. Efficient trim with short fuselage
3. Improved lateral handling (lower effective dihedral, reduced adverse yaw)
4. Potential for aeroelastic control: prevent aileron reversal, active flutter control
5. Reduced tendency for pitch-up, control at high alpha
6. Reduced vertical tail height
7. Possible reduction in wake vortex strength

Configuration:

1. Improved aero/structural performance through span loading, potential for reduced wetted area
2. Effective use of redistributed wetted area reduces high lift system cost or TO thrust / noise, potential for laminarization.
3. Some advantages of all-wing design with reduced risks: egress, windows, growth, structure, acceptability
4. 2 wing-mounted engines reduce obstacle problem with outer engine / engine out yaw
5. Single deck in wing facilitates loading, emergency egress

Disadvantages:

1. Details of emergency egress remain uncertain
2. Aerodynamics of thick inboard sections still an issue
3. Aeroelastics may be controllable but may need to be controlled

Conclusions

A look at nonplanar wing concepts suggests that such configurations do offer potential performance benefits. This is especially true when the concept is fully exploited by re-sizing or even redesigning the aircraft.

In addition to reductions in vortex drag, some of configurations mentioned here have desirable effects on structures, stability and control characteristics, vortex wake hazards, and other practical considerations.

The split tip design demonstrates that by manipulating the wake shape as well as the wing shape, some of the advantages of nonplanar wings may be obtained even with planar wings, and the possible applications of this idea warrant further study.

The C-wing configuration remains an intriguing design concept with many beneficial characteristics when applied to a large aircraft design. The implications of this approach remain to be more fully explored.

Conclusions

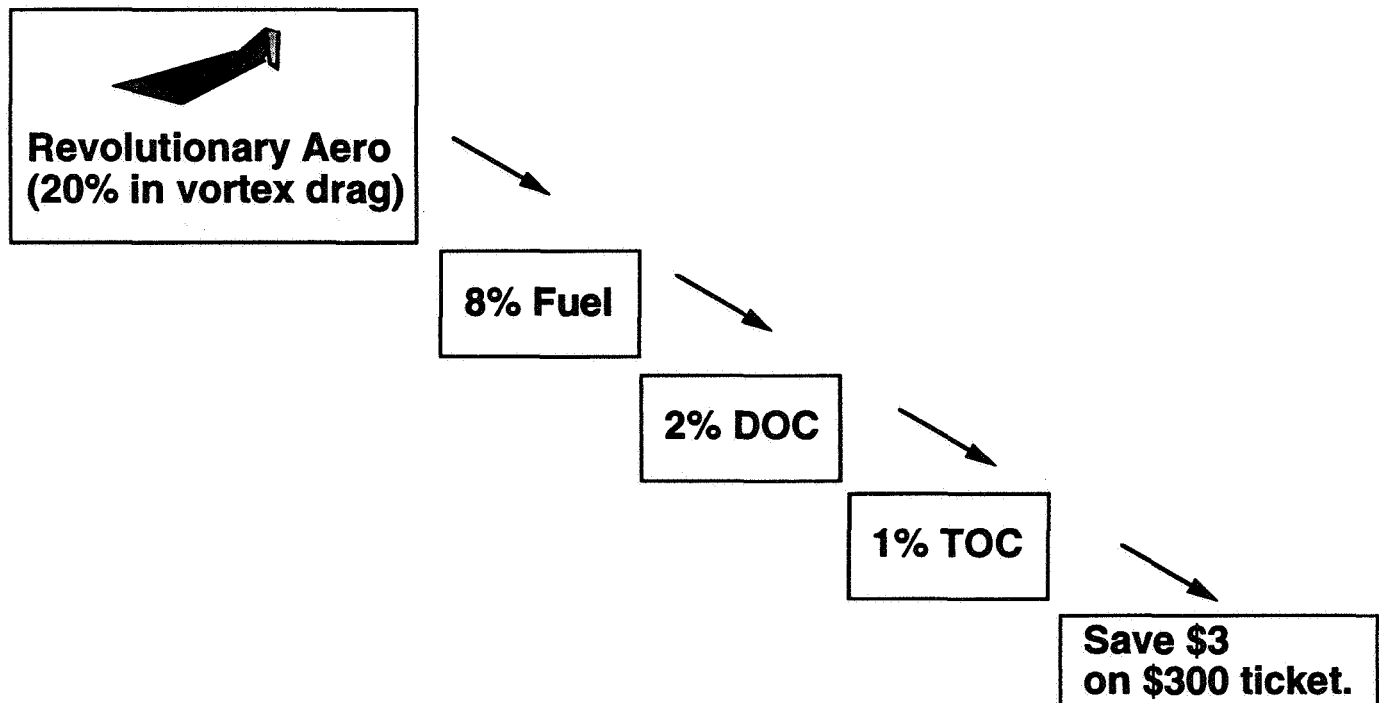
- **Nonplanar wings provide potential performance benefits**
- **Other useful characteristics**
- **Split tip demonstrates high span efficiency**
- **C-Wing characteristics intriguing but not fully explored**

Post Script

The direct application of these concepts to an existing aircraft are less than overwhelming. As illustrated in the figure below, if a 20% reduction in vortex drag were achieved by an existing airplane and the airlines passed the savings on to the customers directly, we would see a very modest reduction in ticket price (about \$3 on a \$300 ticket). Although this savings would have major implications for airline profitability, most passengers would not be impressed by the savings. If the concept is used to redesign the airplane, as in the C-wing example here, not only is the savings increased, but an otherwise infeasible design may become feasible.

The Bigger Picture

Aerodynamics and Ticket Price



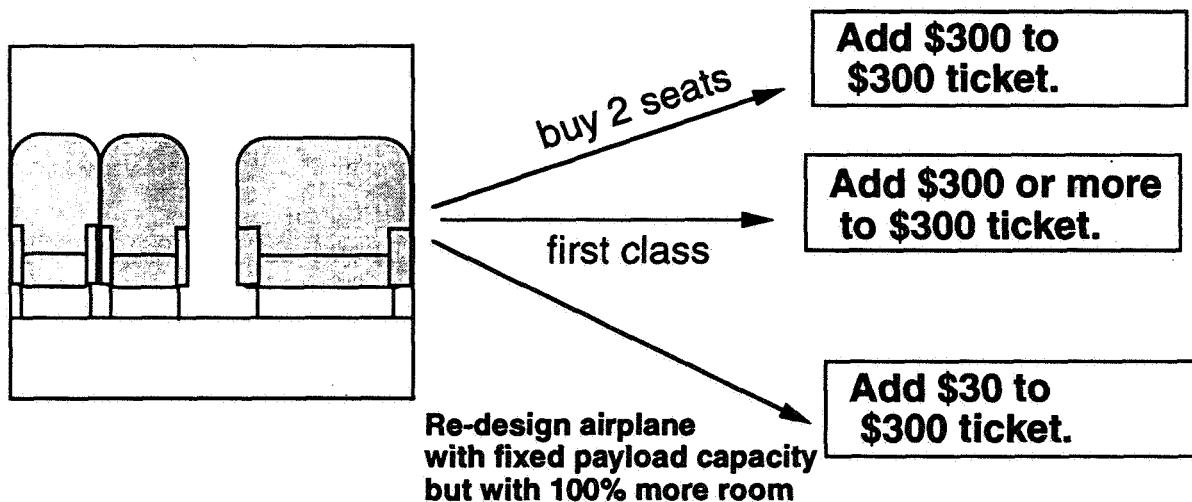
Post Script

The direct insensitivity of ticket price to drag might be exploited as shown below. By re-designing an aircraft with fixed payload capacity, but with twice the floor space for each passenger, the fare would have to be increased by about \$30 on a \$300 ticket*. This is very reasonable, but might still be unacceptable in the highly elastic commercial transportation market. Nonetheless it is my hope that advances in aerodynamics and other disciplines can be employed to do more than just marginally lower the cost of air transportation, but rather improve its safety and comfort.

*This is the result of a numerical optimization study undertaken during my 11 hour trip from San Francisco to this conference.

The Cost of Comfort

Cost of Doubling Passenger Space



References

- Cone, C. D., "The Theory of Induced Lift and Minimum Induced Drag on Non-Planar Lifting Systems," NASA TR-R-139, 1962.
- De Young, J., "Induced Drag Ideal-Efficiency Factor of Arbitrary Lateral-Vertical Wing Forms," NASA CR-3357, Dec. 1980.
- Gage, P., "New Approaches to Optimization in Aerospace Conceptual Design," Ph.D. Thesis, Stanford University, Dec. 1994.
- Gallman, J.W., Kroo, I., Smith, S.C., "Design Synthesis and Optimization of Joined-Wing Transports," AIAA 90-3197, Sept. 1990.
- Heyson, H. H., Roebe, G. D. and Fulton, C. L. "Theoretical Parametric Study of the Relative Advantages of Winglets and Wing-Tip Extensions," NASA TP 1020, 1977.
- Jones, R., Lasinski, T., "Minimum Induced Drag of Wings with Winglets", NASA TM-81230, Sept. 1980.
- Kroo, I., "A General Approach to Multiple Lifting Surface Analysis and Design," AIAA 84-2507, Oct. 1984.
- Lange, R.H., Cahill, J.F., et al., "Feasibility Study of the Transonic Biplane Concept for Transport Aircraft Application," NASA CR 132462, Lockheed-Georgia Company, June 1974.
- Letcher, J.S., "V-Wings and Diamond-Ring Wings of Minimum Induced Drag," J. of Aircraft, Vol. 9, No. 8. 1972.
- Lundry, J. L. and Lissaman, P. B. S. , "Minimum Induced Drag on Non-planar Wings," J. Aircraft, Vol. 5, No. 1, 1968, pp. 17-21.
- McMasters, J.H., Kroo, I.M., "Advanced Configurations for Very Large Subsonic Transport Airplanes," NASA Workshop on Potential Impacts of Advanced Aerodynamic Technology, portions published in NASA TM 109154, Sept. 1994.
- Munk, M. M., "The Minimum Induced Drag of Aerofoils," NACA Report 121, 1921.
- Smith, J. H. B., "Wing Tip Flows and Wing Devices (Symposium): Introductory Remarks," Aeronautical J., Dec. 1987, pp. 443-445.
- Smith, S.C., "A Computational and Experimental Study of Nonlinear Aspects of Induced Drag," Ph.D. Thesis, Stanford University, June 1995.
- van Dam, C.P., "Induced Drag Characteristics of Crescent-Moon-Shaped Wings," J. of Aircraft, Vol. 24, No.2, 1987.
- van Oossanen, P. , Joubert, P. N., "The Development of the Winged Keel for Twelve-Metre Yachts," J. Fluid Mechanics, Vol. 173, 1986, pp. 55-71.
- von Karman, T., Burgers, J.M., "General Aerodynamic Theory—Perfect Fluids," Vol. II of Aerodynamic Theory, W.F. Durand, ed., 1935.
- Wolkovitch, J., "The Joined Wing: An Overview," J. of Aircraft, March 1986.

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***APPLICATION OF PNEUMATIC LIFT AND CONTROL SURFACE
TECHNOLOGY TO ADVANCED TRANSPORT AIRCRAFT***

by

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**TRANSPORTATION BEYOND 2000:
ENGINEERING DESIGN FOR THE FUTURE**

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Introduction

The application of pneumatic (blown) aerodynamic technology to both the lifting and the control surfaces of advanced transport aircraft can provide revolutionary changes in the performance and operation of these vehicles, ranging in speed regime from Advanced Subsonic Transports to the High Speed Civil Transport, and beyond. This technology, much of it based on the Circulation Control Wing blown concepts, can provide aerodynamic force augmentations of 80 to 100 (i.e. return of 80-100 pounds of force per pound of input momentum from the blowing jet). This can be achieved without use of external mechanical surfaces. Clever application of this technology can provide no-moving-part lifting surfaces (wings/tails) integrated into the control system to greatly simplify aircraft designs while improving their aerodynamic performance. Lift/drag ratio may be pneumatically tailored to fit the current phase of the flight, and takeoff/landing performance can be greatly improved by reducing liftoff/touchdown speeds and ground roll distances. Alternatively, great increases in liftoff weights and payloads are possible, as are reductions in wing and tail planform size, resulting in optimized cruise wing designs. Furthermore, lift generation independent of angle of attack provides much promise for increased safety of flight in the severe updrafts/downdrafts of microbursts and windshears, which is further augmented by the ability to sustain flight at greatly reduced airspeeds. Load-tailored blown wings and blown wing tips can also reduce tip vorticity during high-lift operations and the resulting vortex wake hazards near terminal areas. Induced drag due to lift can also be decreased. Reduced noise may also be possible as these jets can be made to operate at low pressures and reduce noise-producing turbulence.

The following presentation will support the above statements through discussions of recent experimental and analytical research and development of these advanced blown aerodynamic surfaces, portions of which have been conducted for NASA. Also to be presented will be predicted performance of advanced transports resulting from these devices. Suggestions for additional innovative high-payoff research leading to further confirmation of these concepts and their application to advanced efficient commercial transport aircraft.

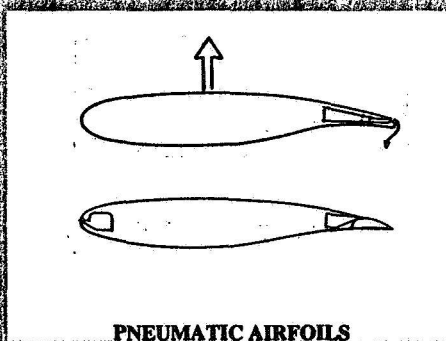
APPLICATION OF PNEUMATIC LIFT & CONTROL SURFACE TECHNOLOGY TO ADVANCED TRANSPORT AIRCRAFT

"TRANSPORTATION BEYOND 2000"

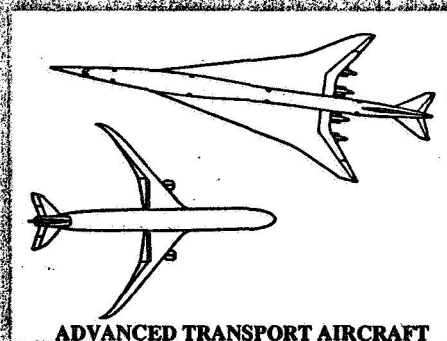
September 27, 1995

by

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PNEUMATIC AIRFOILS

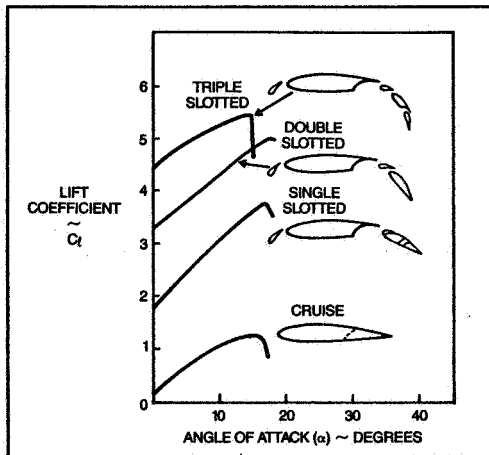


ADVANCED TRANSPORT AIRCRAFT

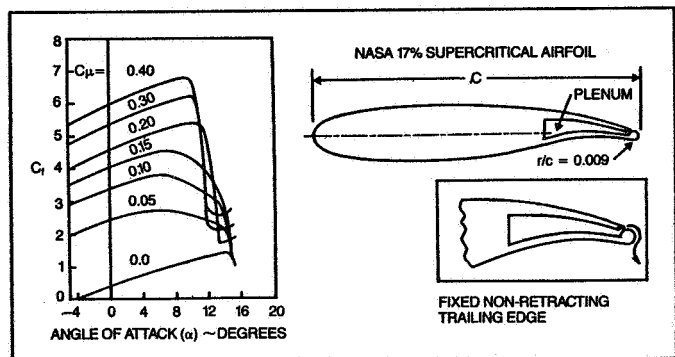
- **No-Moving-Part Aerodynamic Force Augmentor**
- **Pneumatic Control Surfaces**
- **Safety of Flight**
- **Simplicity & Synergism: Aero/Propulsion/Stability & Control**

Comparison of Circulation Control Wing and Mechanical High-Lift Systems

The application of tangential blowing to round or near-round trailing edges of helicopter rotor blade sections has been under development and flight testing for a number of years. Very high lift augmentation, ($\Delta C_l/C_{\mu} = 80-100$ without any moving flap components) was verified during two-dimensional (2-D) wind-tunnel testing. This suggested the application to high-lift systems of fixed wing aircraft. As shown in the figure below, the application of a trailing edge radius equal to 0.9 % wing chord produced maximum lift coefficients nearing 7.0, and values of 6 at $\alpha = 0^\circ$. The real potential is the very low blowing coefficient ($C_{\mu} = \text{mass flux} \times \text{jet velocity} / qS$) at which these values are achieved; these coefficients could conceivably be obtained from direct bleed of existing engines (to be discussed later). An interesting comparison between the blown airfoil and the multi-element mechanical high-lift systems is shown. It required double or triple-slotted flaps and mechanical leading edges to achieve lift performance comparable to the blown no-moving-part CCW/Supercritical section shown. The following figures show the confirmation of blown high-lift augmentation during flight test and further airfoil/wing developments as background. These lead up to recent developments of advanced pneumatic high-lift and control-surface configurations and applications.



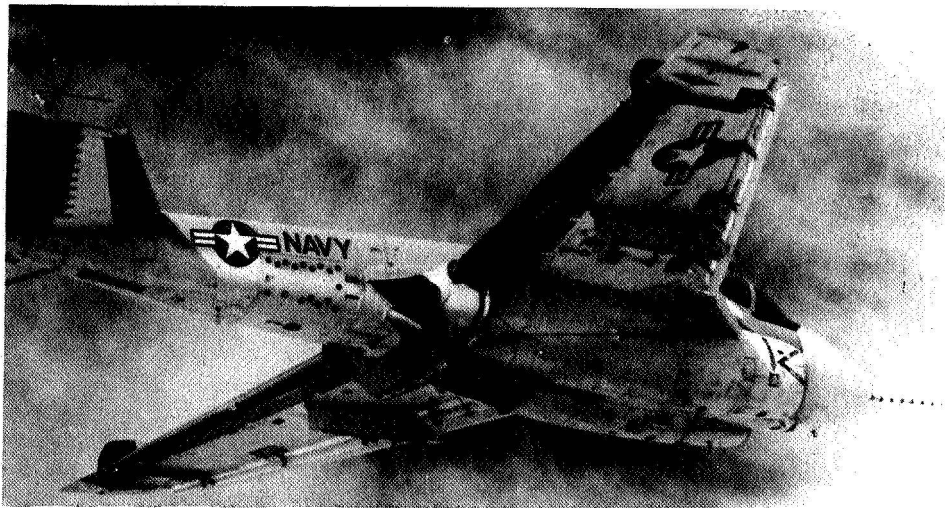
MULTI-ELEMENT MECHANICAL HIGH-LIFT AIRFOILS



NO-MOVING-PART CCW/SUPERCritical AIRFOIL

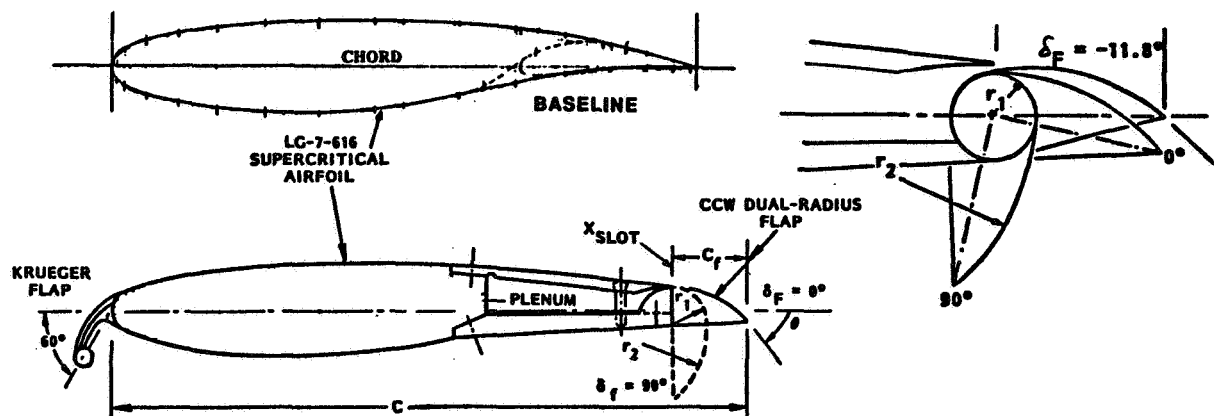
The Flight Test of the CCW Concept on the A-6/CCW Flight Demonstration Aircraft

After a series of 2-D airfoil and 3-D developmental wind-tunnel investigations, a fixed Circulation Control Wing (CCW) trailing edge was installed on a Grumman A-6 Intruder flight-test aircraft for a proof-of-concept program. The high-lift system was fixed to the existing wing with air supply lines connected externally to the existing J-52 turbojet engine bleed ports. In this somewhat limited configuration a maximum C_{μ} of 0.26 was available. Flight test results confirmed an increase of 85% in maximum lift coefficient relative to the existing Fowler-flap/leading-edge-slat high-lift system; but more importantly, an improvement of 140% in usable approach/takeoff lift coefficient was confirmed. Limited STOL performance testing showed reductions in approach takeoff speeds of 30-35% and ground roll reductions of 60-65% relative to the standard A-6. Actual measured ground rolls of 600-700 feet and flight speeds as low as 65 knots showed that a light-weight A-6/CCW could have operated from a big-deck aircraft carrier without use of catapult or arresting gear. Also, the new system allowed up to a 75% increase in A-6 liftoff payload for the same ground roll.



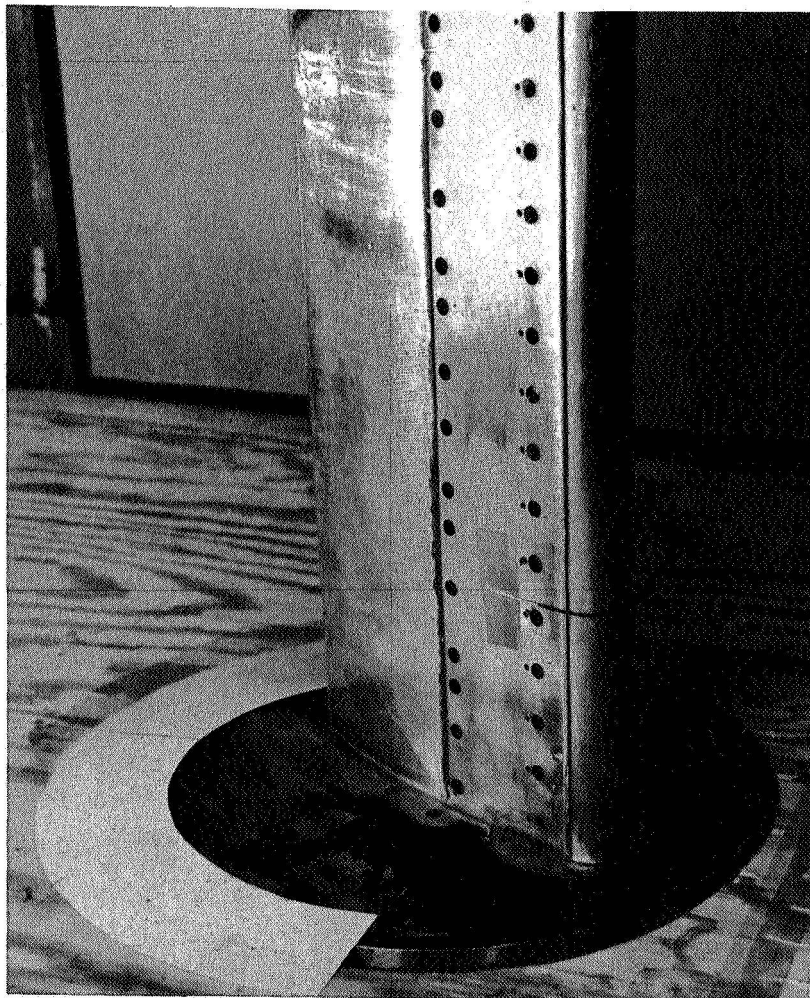
Dual-Radius Circulation Control Wing Configuration with Krueger Leading-Edge Device

The one disadvantage of the round or near-round CCW configuration was high base drag in cruise. An alternate configuration known as the Dual-Radius CCW airfoil was developed at David Taylor Naval Ship R and D Center and at Lockheed Aeronautical Systems Company-Georgia. As shown here applied to a 17% supercritical airfoil, this short-chord flap rotated up to 90° about a lower surface hinge point, exposing a small-radius (r_1) CCW surface. The upper surface of the small flap (normally 10-11% chord, but as low as 5% chord has been demonstrated) was a second much larger radius (r_2) which provided excellent jet turning when deflected to flap angles as high as 90° . When retracted, a sharp trailing edge existed for cruise, and the large upper surface radius yielded little if any aft flow separation. The airfoil shown here was tested extensively at LASC-Georgia. A mechanical Krueger leading-edge flap deflected 60° was initially installed to keep the leading edge flow attached at the very large supercirculation and high upwash produced by the blown trailing edge. Results are shown on the following pages.



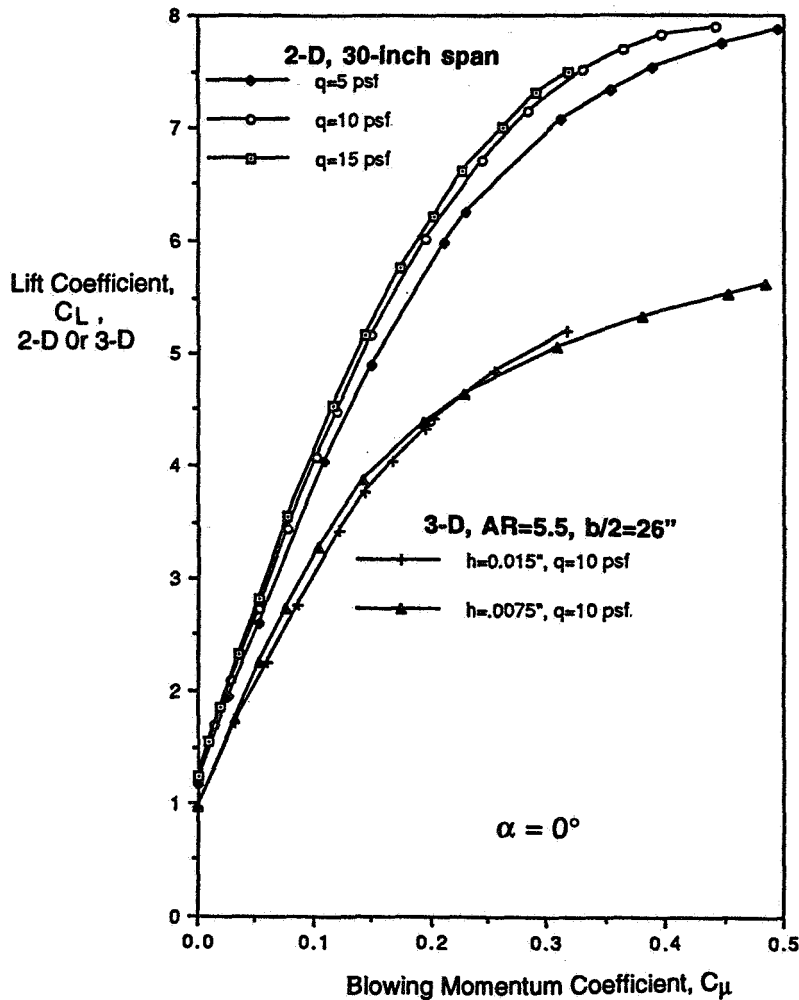
Aft View of Dual-Radius CCW Airfoil Showing Jet Turning and Attachment to 90° CCW Flap

This picture shows a 2-D airfoil with the dual radius CCW flap installed, mounted in the subsonic Model Test Facility research wind tunnel at GTRI. The CCW flap is deflected 90°, which allows turning of the tangential jet to as much as 130-135° down from the aft chordline. Jet attachment is shown by the tuft. Note that the very high flow entrainment and supercirculation allow this airfoil to generate positive large lift at very large negative angles of attack. This test setup allowed various flap deflection angles to be evaluated. It also allowed the 2-D airfoil to be withdrawn through the floor to produce a 3-D rectangular planform wing of constant airfoil section to investigate three-dimensional loading and tip effects.



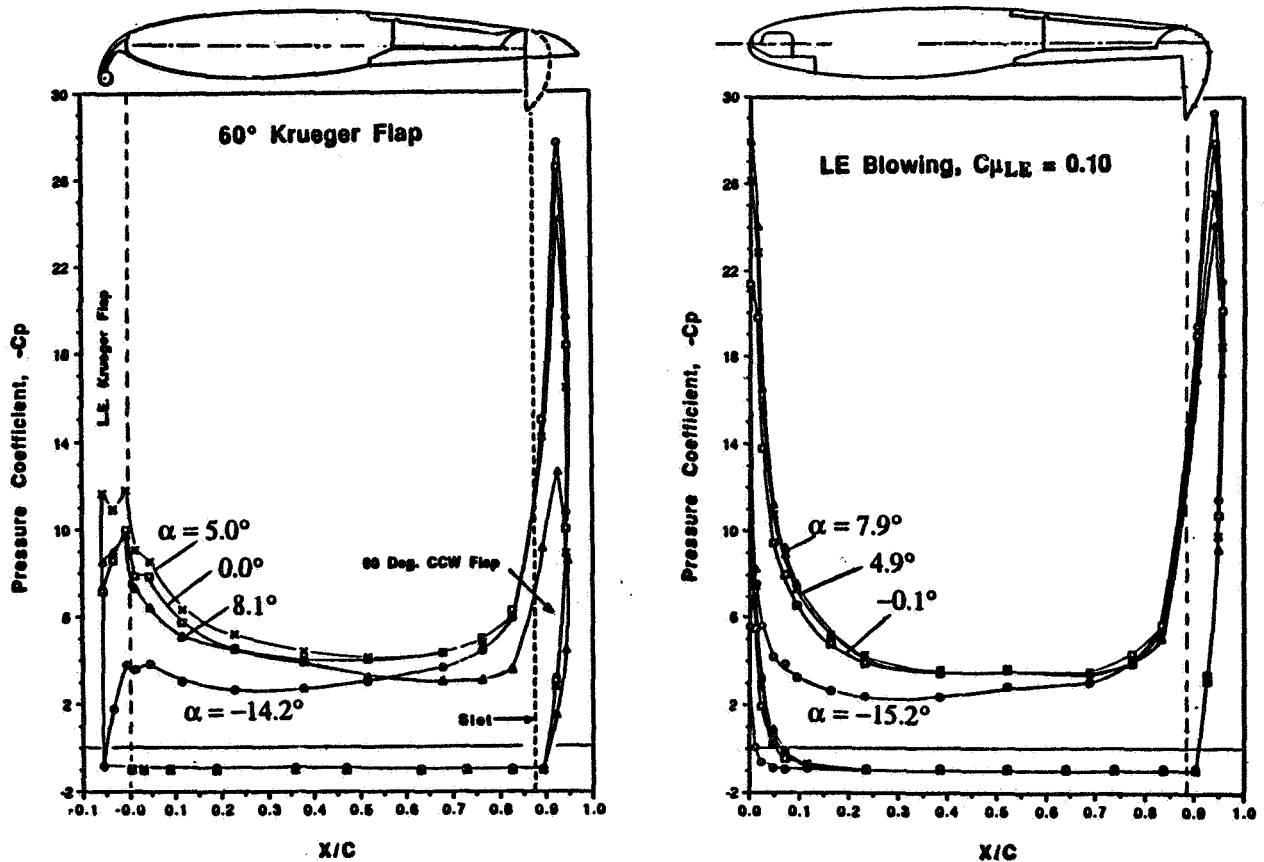
2-D CCW Lift Comparison Showing 3-D and Tip Vortex Effects

These data show lift performance at $\alpha=0^\circ$ for both the 2-D dual-radius-CCW airfoil with a 60° Krueger LE flap and 90° CCW flap and an aspect-ratio 5.5 semi-span wing created when this airfoil model was retracted through the tunnel floor. Two-dimensional lift values of nearly 8 were generated for C_μ of 0.4. The lift improvement of this dual-radius flap over the previous round CCW trailing edge is approximately 35% and is accompanied by greatly reduced cruise drag (to be discussed later). The 2-D lift improvement represents a factor of 2 to 4 increase over the mechanical flaps of previous slides at $\alpha=0^\circ$. Note also the lift reductions that occur due to tip vorticity and span wise effects when the airfoil is converted to a 3-D semi-span wing. Nevertheless, the resulting C_L values of greater than 5 at $\alpha=0^\circ$ are still appreciable.



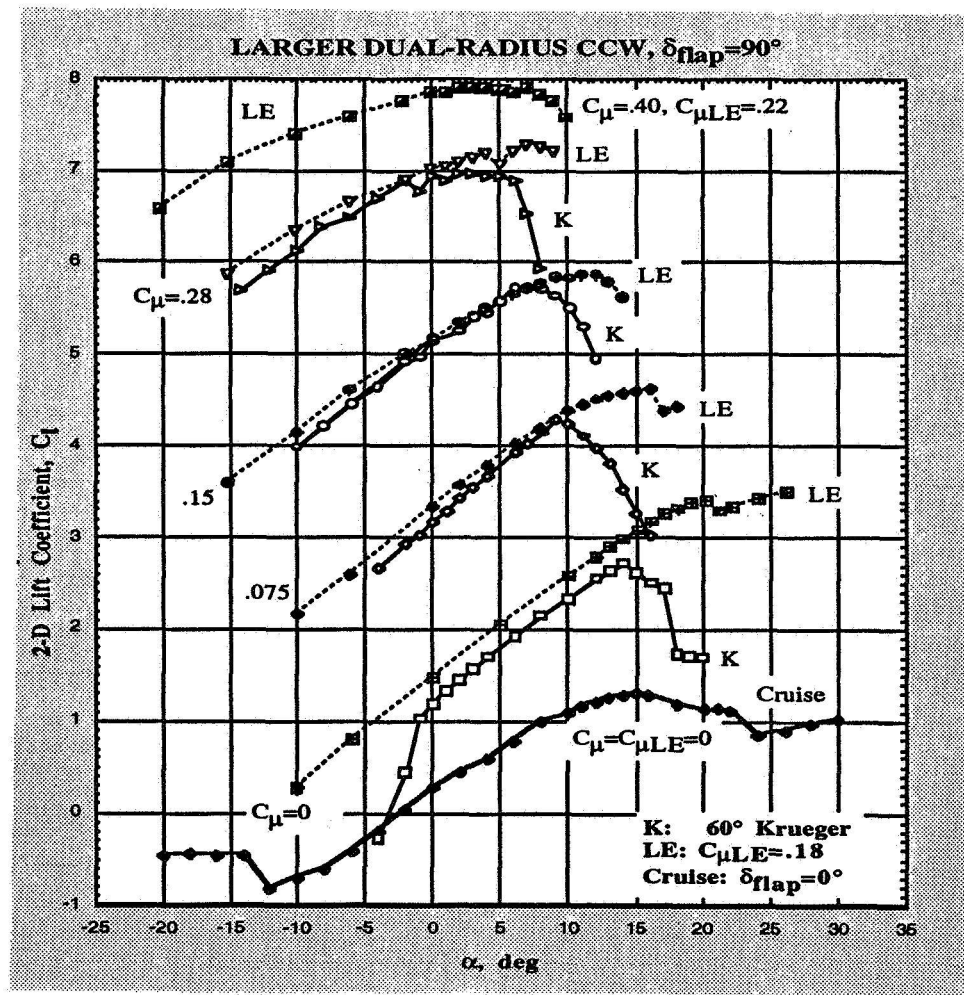
Blown Leading Edge Effectiveness on CCW Airfoils, $C_{\mu} = 0.28$

An effective leading edge (LE) device is essential to retain LE flow attachment at high angle of attack and high supercirculation levels. Whereas the mechanical Krueger LE device at 60° deflection had been an effective device in the previous tests, its ability to perform at high incidence and high lift reached limitations. The pressure distributions below at an intermediate C_{μ} confirmed that a LE separated region formed and expanded as incidence was increased. It was desired to eliminate this problem, as well as the mechanical LE device, from the pneumatic airfoil. Thus a blown LE was installed in the present dual-radius airfoil model. Its effect in eliminating LE separation is shown in the pressure distributions below. Not only does the LE flow remain attached for all conditions shown, but also, the leading edge effectiveness can be adjusted without moving parts merely by varying the blowing rate. Thus, leading edge stall protection could be coupled to trailing edge supercirculation generation merely by coordinating two separate valves. Also, unlike LE flaps or slats, there is no lower-surface LE stall occurring at lower wing incidence. The LE blowing is merely terminated to return the airfoil to cruise conditions; blowing is thus transparent in leading-edge operation.



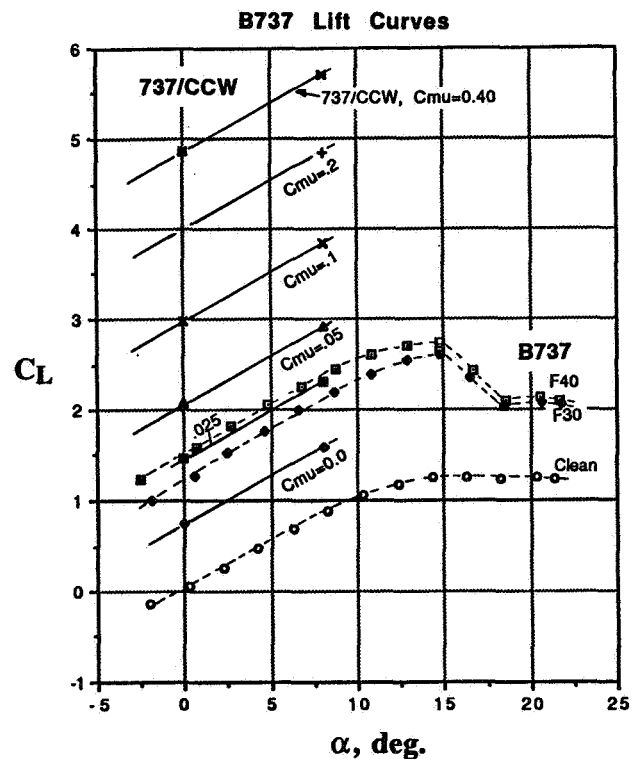
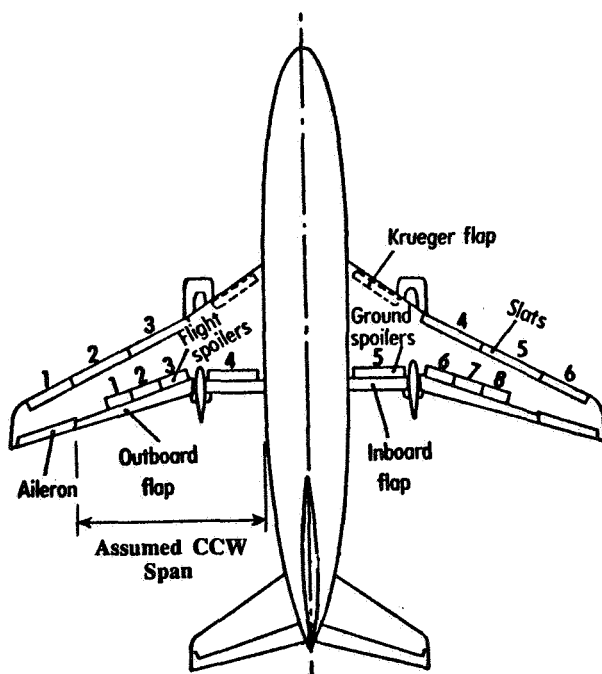
Blown Leading Edge Lift and Stall Improvements

Blown airfoil lift curves are shown below to compare the Krueger flap mechanical leading edge (identified as K) with the blown leading edge (LE) of the previous page. For reference, the clean cruise airfoil is also shown. Note here the Krueger lower surface stall at $C_{\mu}=0$, and that for any constant value of trailing edge C_{μ} , the LE blowing shows significantly higher stall angle, as well as, greater lift at lesser incidence. This is because, unlike mechanical LE devices at low incidence the LE blowing itself adds to the supercirculation of the airfoil. Leading edge blowing alone was found to traverse all the way to the trailing edge dual-radius flap and remain attached to at least a portion of the flap arc, thus augmenting lift. Thus, a non-moving pneumatic LE and a short-chord dual-radius CCW trailing edge yielded very high lift augmentation even at $\alpha=0^{\circ}$.



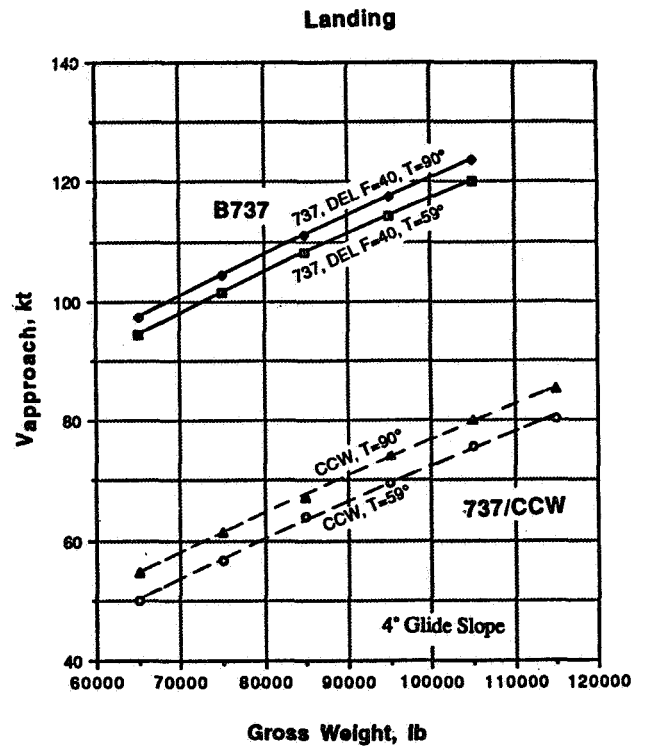
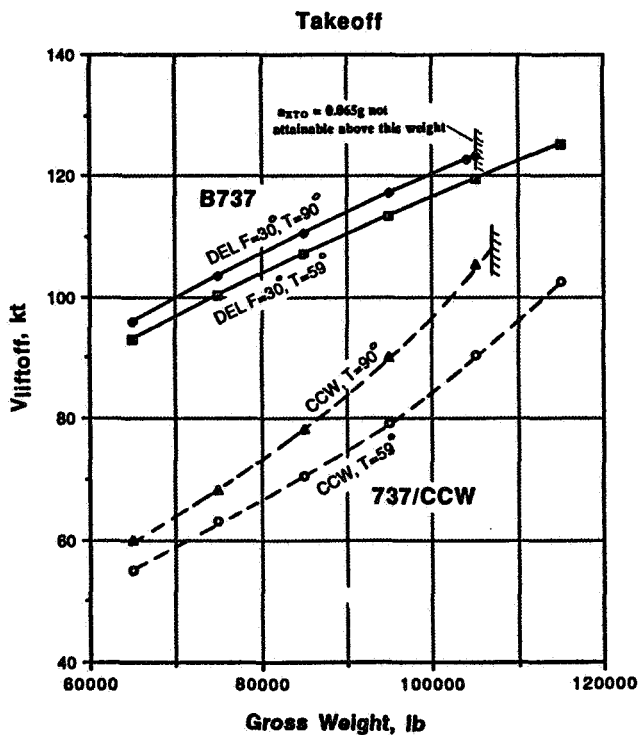
Boeing 737 and 737/CCW High-Lift Systems

To evaluate the payoffs of the dual-radius CCW airfoil, its 2-D characteristics were analytically applied to modify the aerodynamic characteristics of a current day commercial transport, the 737. The airfoil configuration used was the dual-radius CCW with the Krueger LE flap of the previous slide, and with the flap at 90°. Details of this analysis are provided in AIAA Paper 93-0644 by Englar, et. al., but results are summarized in the next few slides. For a fair comparison, the CCW flap spans only the existing 737 flap span, as shown below, although full-span blowing would provide much better aerodynamic performance. The resulting lift curves are also shown below. Since accurate prediction of full-scale blown aircraft stall angle would be difficult at this point, it was assumed that the 737/CCW and the baseline 737 aircraft took off and landed at comparable incidence (α) values. Significant increase in lift capability due to CCW is seen for both the takeoff and landing conditions.



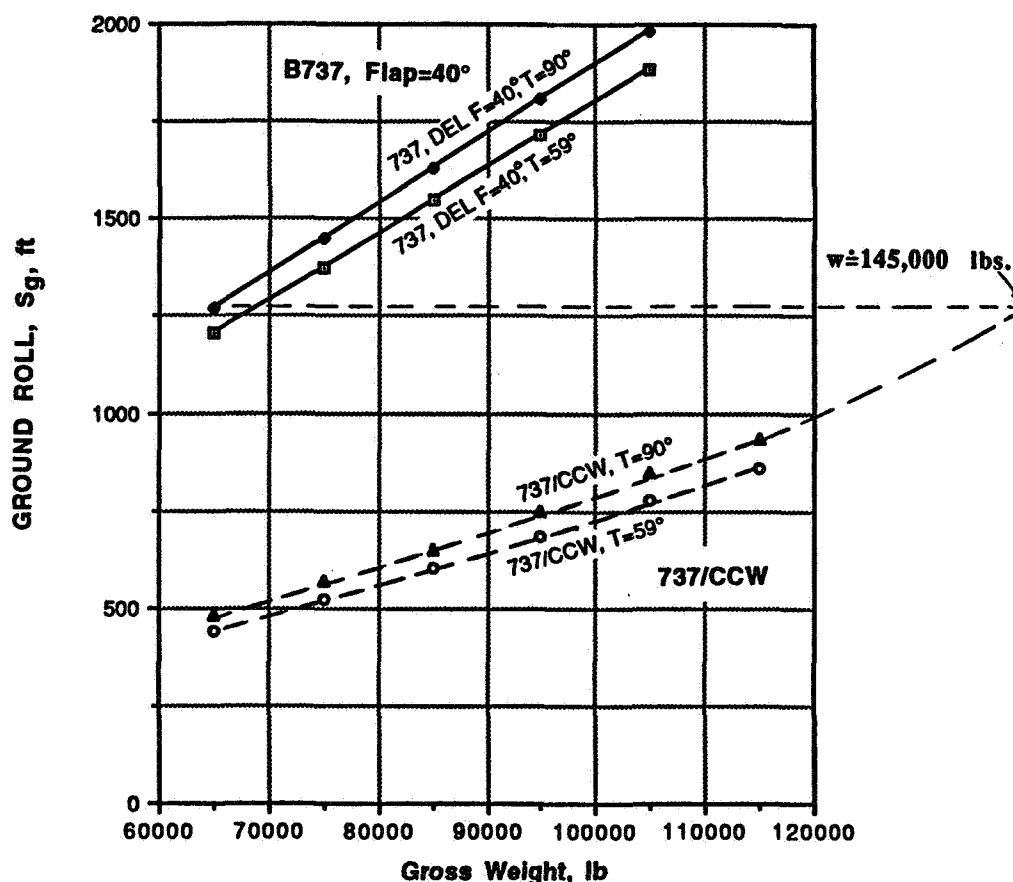
Predicted Boeing 737 and 737/CCW Takeoff and Approach Speeds

Terminal area speeds of the conventional 737 are a function of gross weight, flap angle and temperature, as shown below. Corresponding 737/CCW speeds vary with available blowing instead of flap angle which is fixed here at 90° . Available blowing corresponds to bleed of existing fan bypass air. Blowing reduces liftoff speeds by between 15 and 40%, depending on aircraft weight and temperature. Approach speeds were decreased by 36 to 47% by blowing. One imagines that these could be even greater reductions if more air were available, say from an onboard APU dedicated to high lift in terminal area operations, but to heating, air conditioning and/or pressurization at other times.



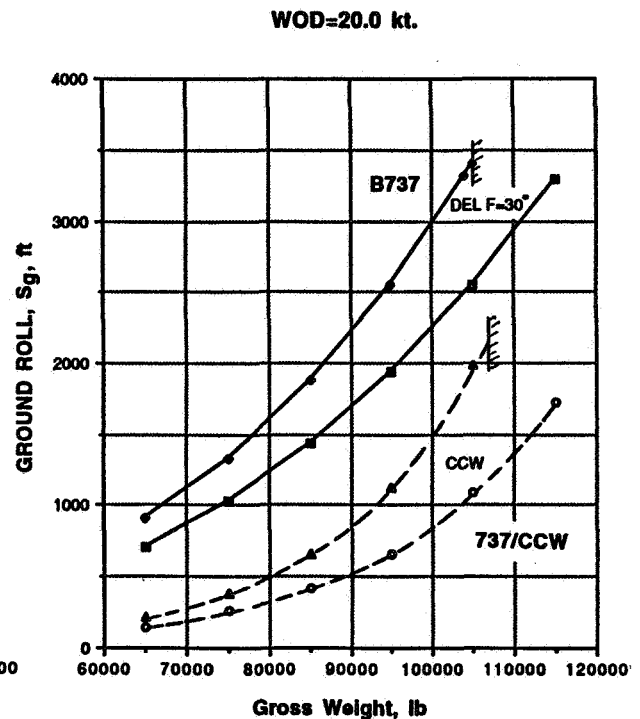
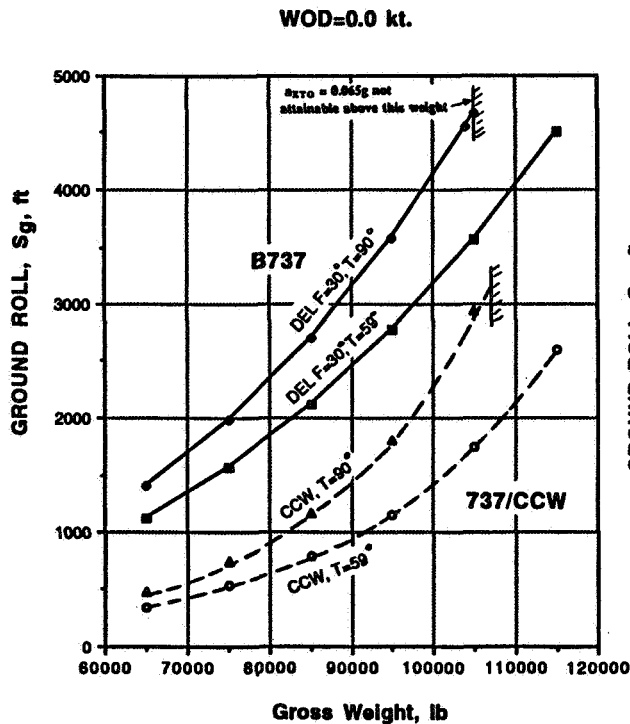
Predicted B737 and 737/CCW Landing Ground Rolls, 0 knot Headwind

Using the previous reduced approach speeds due to blowing, landing ground rolls with braking after a 4° equilibrium approach are reduced by 54-76%, as shown below. An alternate payoff here is to land in the same ground roll distance as the conventional 737 and use the extra landing/lift capability to support extra payload without re-sizing the wing area. For instance, at the 1300-foot ground roll of a 65,000 pound 737, a 123% overload capability is available for the 737/CCW. (No comment is made here on where that extra payload would be stored on the aircraft or if the structure could sustain it, but merely that there is sufficient wing lift to support that extra weight).



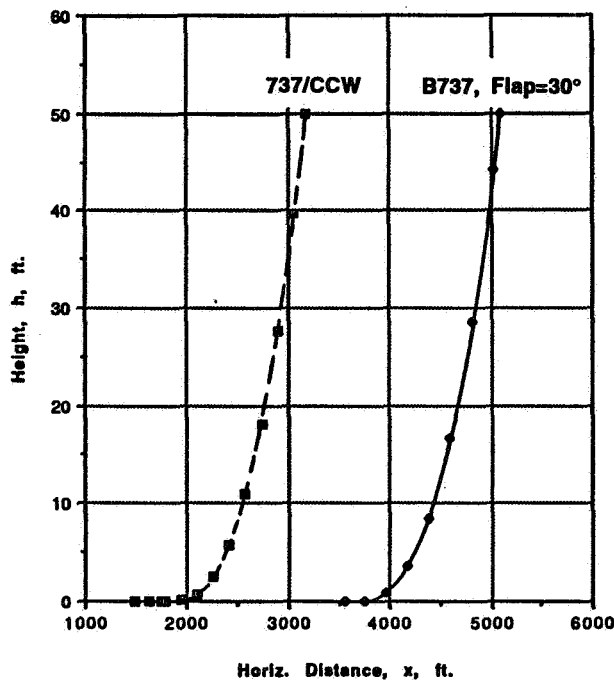
Predicted 737 and 737/CCW Takeoff Ground Rolls at Sea Level

This data applies to previously mentioned takeoff speeds, available with and without blowing, and includes thrust loss due to bleed where appropriate. Blowing has been reduced where necessary to assure that a minimal acceleration at liftoff of 0.065g was available, a Navy one-engine-out restriction. Ground roll reductions from 37 to 80% result, with the greatest reductions being at lighter weights. Again, increases in gross weight that could be lifted airborne at a constant ground roll distance show very large improvements for the blown aircraft over the conventional configuration.

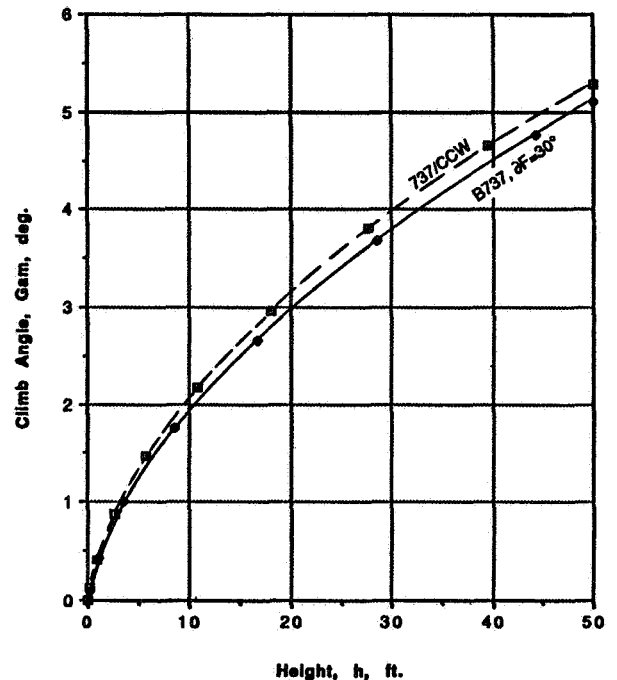


**Predicted B737 and 737/CCW Takeoff Flight Path and Climb Angle, Gross
Weight=105,000 pounds, Temperature=59°, 0 knot Headwind**

These predictions are shown for a heavier value of gross weight, and reveal the reduced distance to climb over a 50 foot obstacle, as well as the slightly larger climb angle available from the blown aircraft. It should be noted here and for the previous slides, that all blown takeoff performance is for the 737/CCW with a 90° flap deflection, which is clearly a high-drag configuration which would probably not yield good L/D values on takeoff. Improved performance should result if the blown flap angle and blowing were optimized for both takeoff and landing.



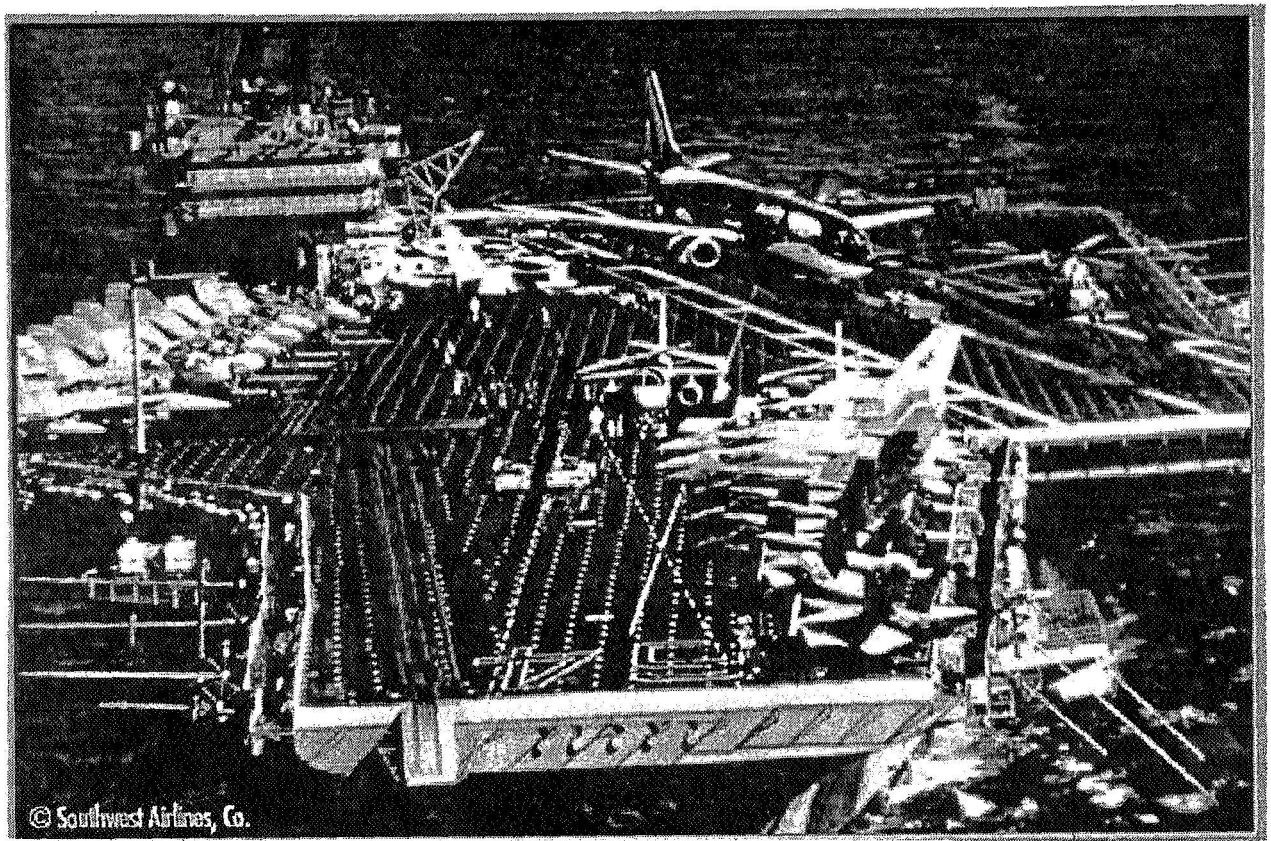
FLIGHT PATH



CLIMB ANGLE

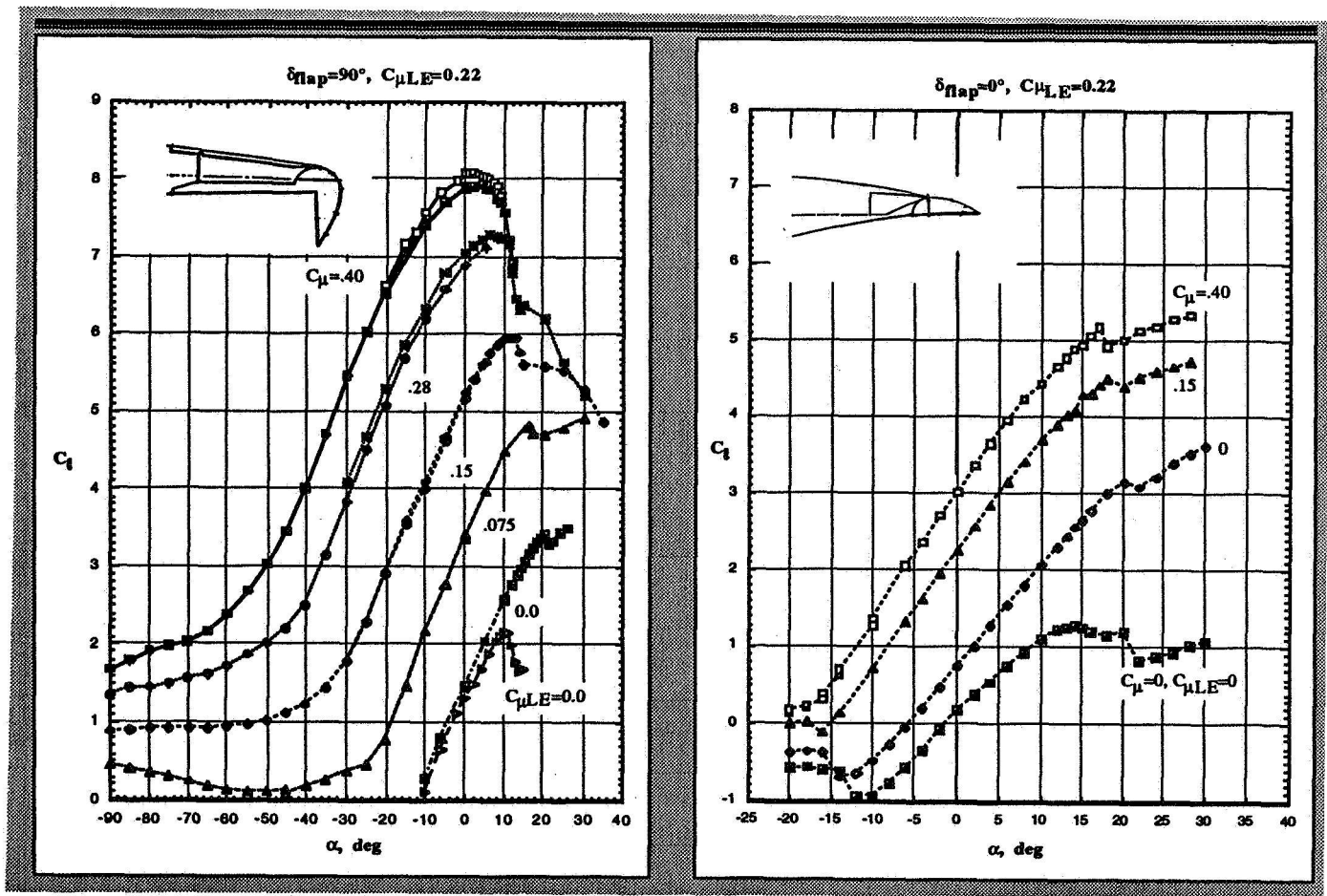
Short Field Capability for Pneumatic Commercial Aircraft (??)

Thanks are due to Southwest Airlines Company for this interesting picture which we downloaded from their World Wide Web home page. The previous data indicates that these ground roll distances, implied in jest here by the airline, are already possible for a light weight 737-CCW commercial aircraft. Given optimization of the flap angle and addition of leading edge blowing, ground rolls of these short distances should be possible for a much larger range of weights for pneumatic commercial airliners.



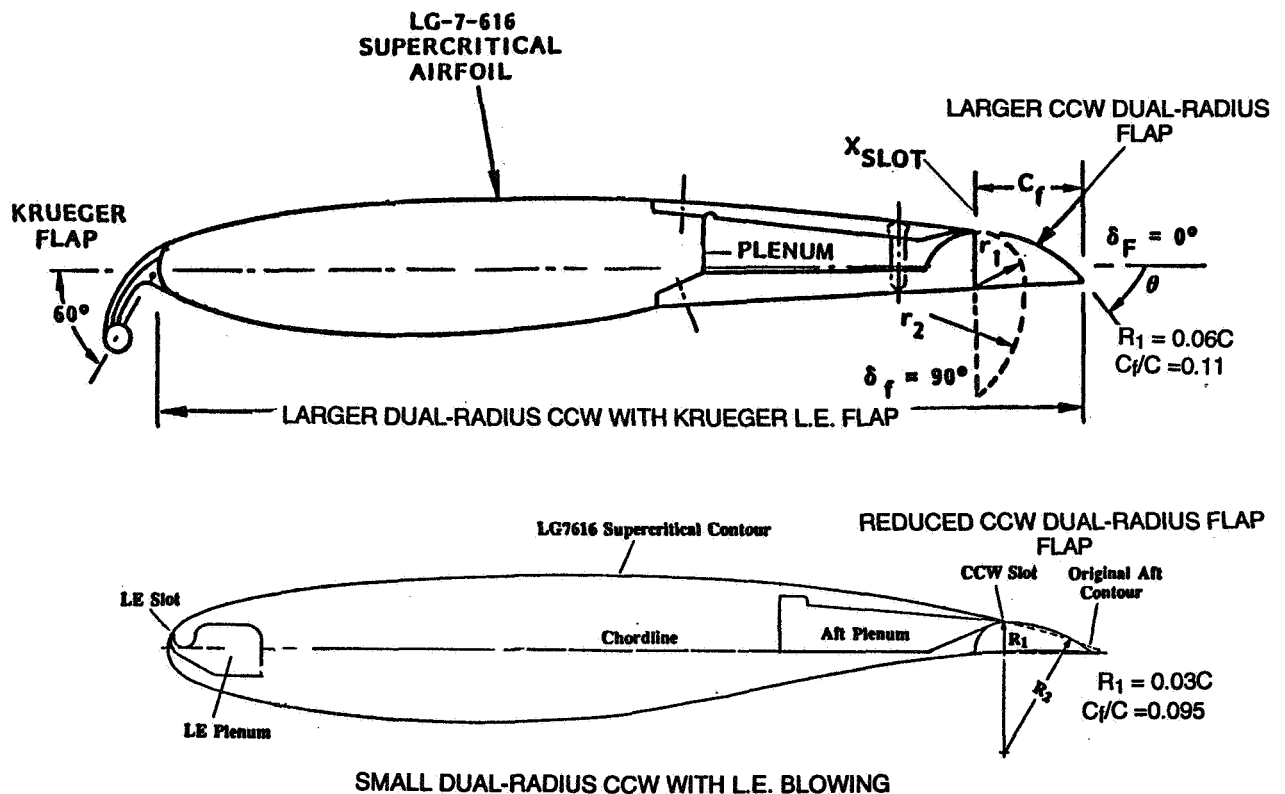
Safety of Flight: Extended α and Lift Ranges, (Larger Dual-Radius CCW Airfoil)

Safety of flight of commercial aircraft is essential in severe weather, including the high updrafts and downwash angles found in microbursts and windshears. Blowing will provide a very interesting safety feature not previously mentioned. At GTRI, we have experimentally evaluated the dual-radius CCW airfoil over a very large range of negative and positive angles of attack. These data were intended to look at blown wings for a tilt-rotor aircraft experiencing large downwash angles over the wing upper surface. These results are shown below, where leading edge blowing is applied to both figures. The left figure is with the CCW flap deflected 90° and shows that for all trailing-edge blowing of $C_{\mu}=0.075$ or more, positive lift coefficient is generated all the way to $\alpha=-90^\circ$, and beyond. On the high positive incidence extreme, a lift coefficient of 5 or more is generated out to $\alpha=30^\circ$, even though stall may be exceeded at higher blowing. Thus, positive lift is possible over 120° angle of attack range for the flap-down configuration. The right figure is data for the cruise airfoil, i.e. flap retracted to 0° . Here, C_l up to 5 is possible without any surface deflected, using only blowing. With these blown airfoils, it is physically possible to maintain a high lift coefficient value on approach or takeoff even if the aircraft undergoes large changes in α due to windshear or microbursts. For instance, using the 90° flap, the aircraft can maintain a section lift coefficient of 5.0 with the aircraft dropping incidence from $\alpha=+30^\circ$ to -32° , merely by increasing flap C_{μ} from 0.075 to 0.40.



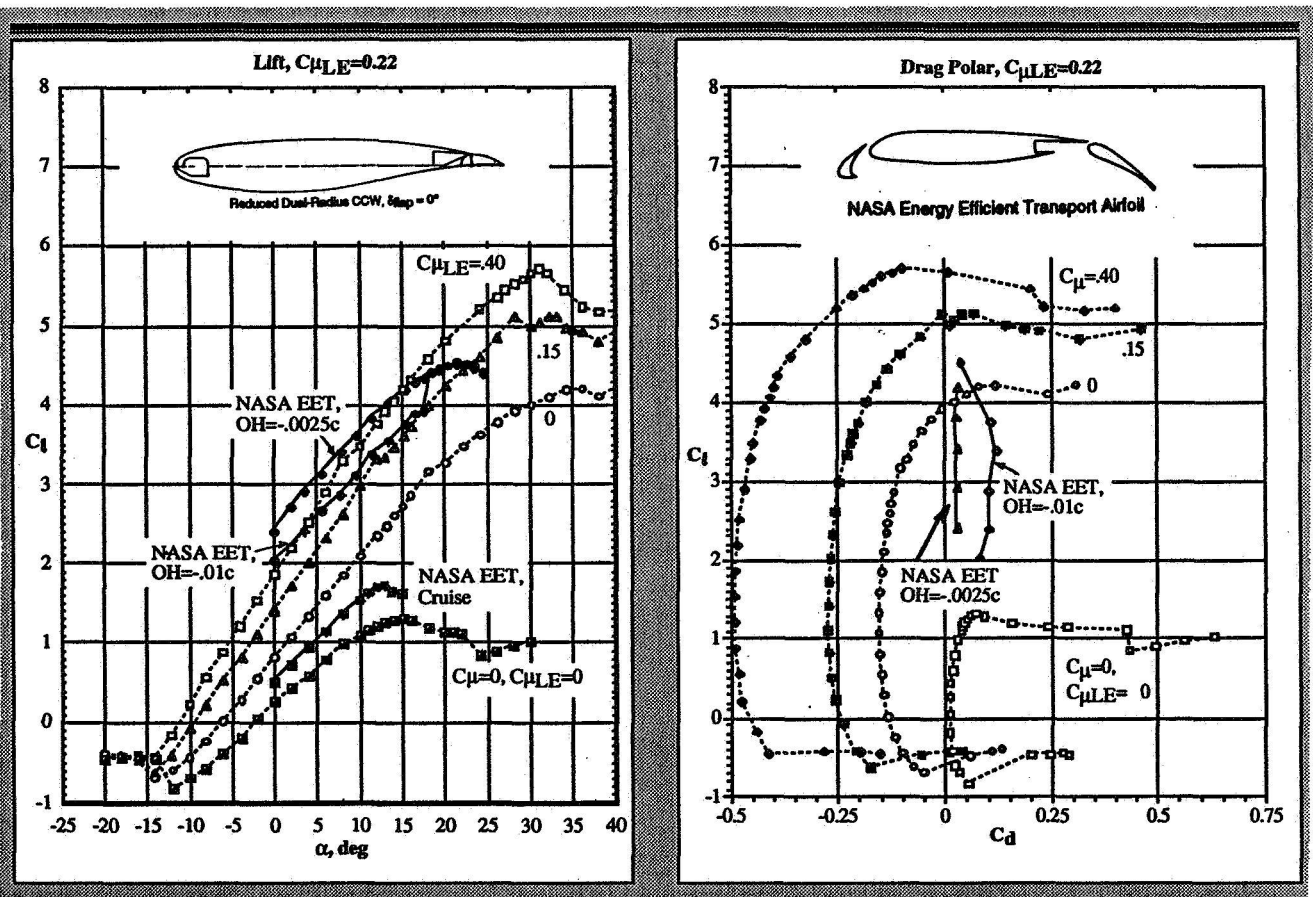
Advanced Dual-Radius CCW/Supercritical 2-D Airfoils

The ultimate goal in the development of pneumatic airfoils is to design one with very high-lift capabilities, no cruise drag penalty, few or no moving parts, and minimal changes to the baseline cruise airfoil configuration. The dual-radius CCW configuration with leading edge blowing as previously discussed was close to this goal. However, to ensure excellent CCW jet turning, an enlarged trailing edge radius had been chosen which exceeded the original supercritical airfoil contour. A more recent configuration is shown below, the small dual-radius CCW airfoil. Here the initial radius (R_1) has been cut in half relative to the previous airfoil so that the undeflected flap falls within the cruise airfoil contour. This produces an initial radius of 3% wing chord and a flap chord of less than 10% wing chord. Again, leading-edge blowing is employed. The same CCW airfoil as previously tested has been modified into this configuration. The following slides will present representative data. It should be noted that the plenums shown are probably oversized relative to actual aircraft application. Here they had to contain pressure recording equipment and static pressure tubing while still not distorting plenum flow.



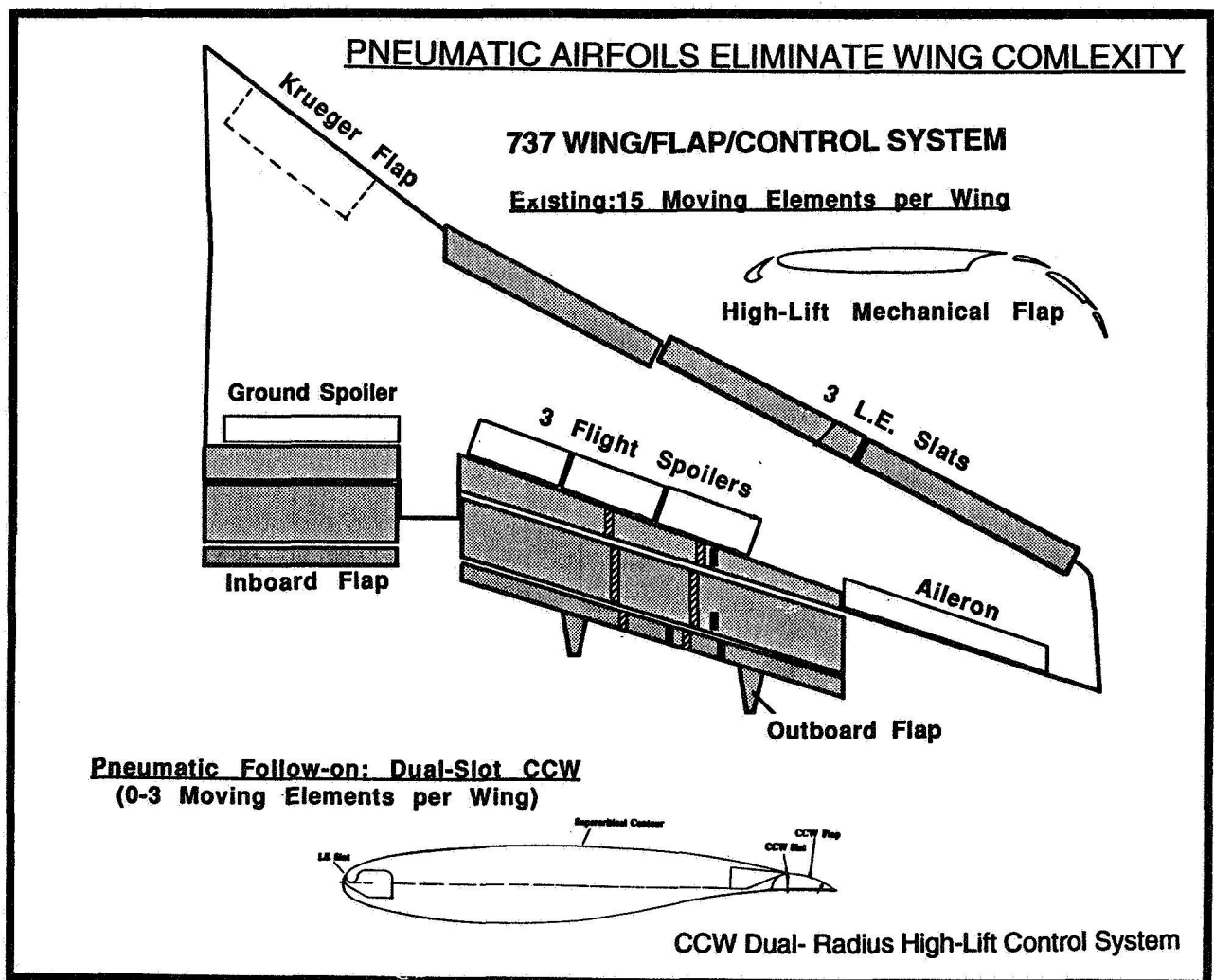
Force Amplification of Small Dual-Radius CCW Airfoil $\delta_{flap}=0^\circ$

At this point, only the undeflected-flap configuration has been evaluated in the tunnel with blowing, but the results are quite enlightening since this represents the cruise airfoil. For reference in the data below, we have included the recent NASA Energy Efficient Transport (EET) airfoil, from AIAA Paper 95-1858. This is a single-slotted flap/slat high-lift airfoil, where the less complex single-slotted flap is used to reduce parts count, complexity, cost, and noise due to turbulence over multi-element flaps. Its cruise airfoil is a 12% thick supercritical airfoil and test Reynolds number ran from 9 to 16 million. The current CCW airfoil is a 17% thick supercritical design with high-lift test Reynolds number less than one million. The results below show that the smaller CCW flap performed better than the larger CCW configuration, probably because of the increased aft camber of the supercritical airfoil. Note that this new airfoil with no moving parts can produce lift coefficients of nearly 6. That compares favorably with the NASA EET airfoil, which, by necessity, is subject to considerable high-lift system optimization, including flap and slat angle, gap, overhang, Reynolds number, etc. Observe the considerable loss in lift performance and drag increase which result when the flap overhang varies slightly from the optimized value ($OH=-0.0025c$). The unblown minimum cruise drag of the CCW airfoil falls in the very acceptable range of around 0.0112-0.0113. (The corresponding cruise drag for the larger dual-radius CCW airfoil at the same conditions was 0.0156-0.0160). The addition of blowing to the cruise airfoil reduces the measured drag to negative values. The negative drag increment produced is on the same order of magnitude as the C_μ applied; that is, there is high thrust recovery from the blown surfaces. The implication here is that airfoil efficiency (l/d) can be very high and can be adjusted during flight by variation in blowing. The fact that this no-moving-part blown airfoil generates greater lift from blowing values on the order of $C_\mu = 0.1$ than the flapped and slatted mechanical airfoil, speaks very highly for this new configuration. It also suggests the possibility of no-moving part blown surfaces to replace aileron, spoiler, rudder, and elevator control surfaces on conventional aircraft.



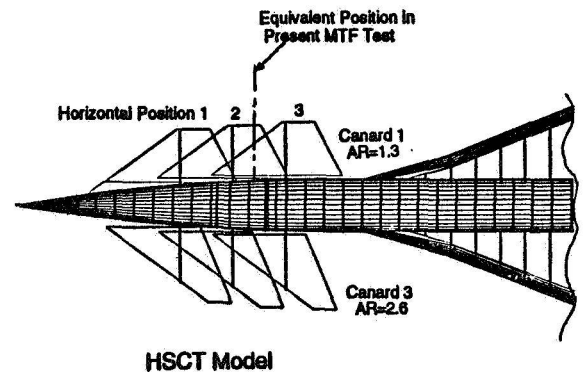
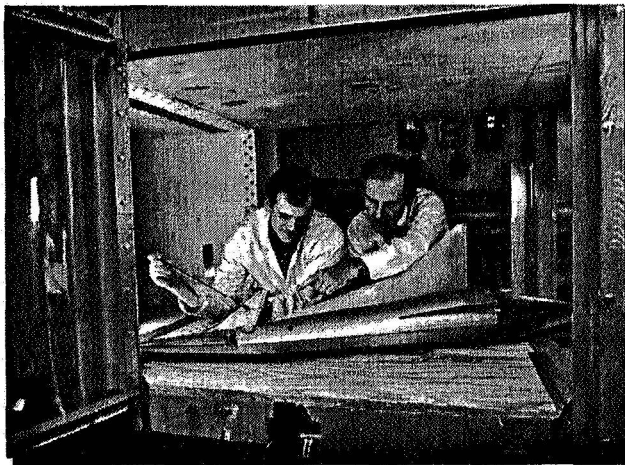
Pneumatic Airfoils Eliminate Wing Complexity

All of the previous data strongly suggest that these new blown airfoils can generate very high lift capability along with reduced drag without use of moving surfaces, or at most, using a small single-element blown flap. This suggests the possibility of simplification of wing complexity and weight. This slide shows a current day commercial transport's wing, which includes 15 moving elements per side for lift generation, stall delay, roll control, and direct lift control. We have seen that the no-moving-parts dual-radius CCW can provide equal or greater lift generation and stall prevention by using blowing. It is also suggested that incremental direct lift and roll control can also be provided by blowing alone. Should even greater lift or roll control be necessary, the small CCW flap can be deflected. Thus it is possible to provide an integrated wing capable of lift, drag, roll, yaw, pitch, and possibly side force control variation without moving surfaces. The improvements in weight, maintainability, safety of flight, and reduction of complexity are evident. In addition, the use of blowing can augment certain of these forces and moments to values which are not obtainable by mechanical surfaces.



Blown Canard on Generic High Speed Civil Transport Model

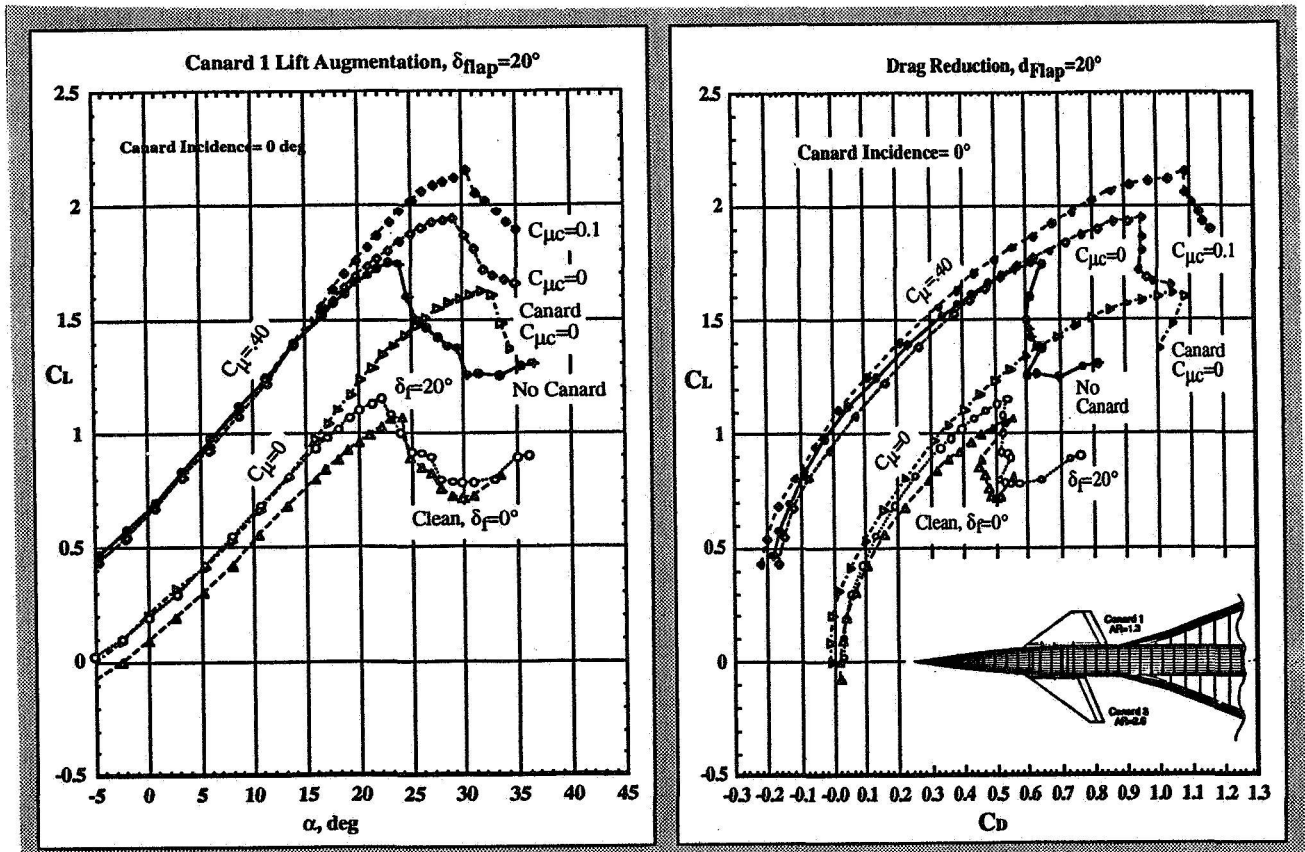
Pneumatic technology is not limited to advanced subsonic transport aircraft. Current designs for proposed High Speed Civil Transport configurations employ highly swept wing designs and achieve high lift augmentation by leading edge vortex generation. This, however, usually requires approach and takeoff at very high angles of attack. This has required additional tail power and such unusual features as nose droop on some designs. Recently, GTRI has investigated for NASA the application of pneumatic technology to HSCT configurations to provide alternative means of lift and angle of attack control. Blown circular-cylinder canards had been applied to National Aerospace Plane configurations to provide pitch control for takeoff, and strong control of wing vortex burst had been discovered to result as well. The same concept was applied here to a generic HSCT configuration. Two blown canards were applied to a half-span NASP model which had a wing planform very similar to HSCT planforms. These canards included Canard 1 (AR=1.3 with forward-swept trailing edge) and Canard 3 (AR=2.6, with aft-swept trailing edge) as shown below. Each of these canards had an aft-blowing slot and a dual-radius-type trailing edge flap. This flap was deflectable, but all of the data shown here were obtained with 0° deflection. The picture shows the higher-aspect-ratio canard with blowing mapped by a tuft. Flow visualization showed that when blowing was applied, the downwash behind the canard delayed vortex burst on the wing because of reduced upwash over the wing leading edge.



Blown Canard Planforms

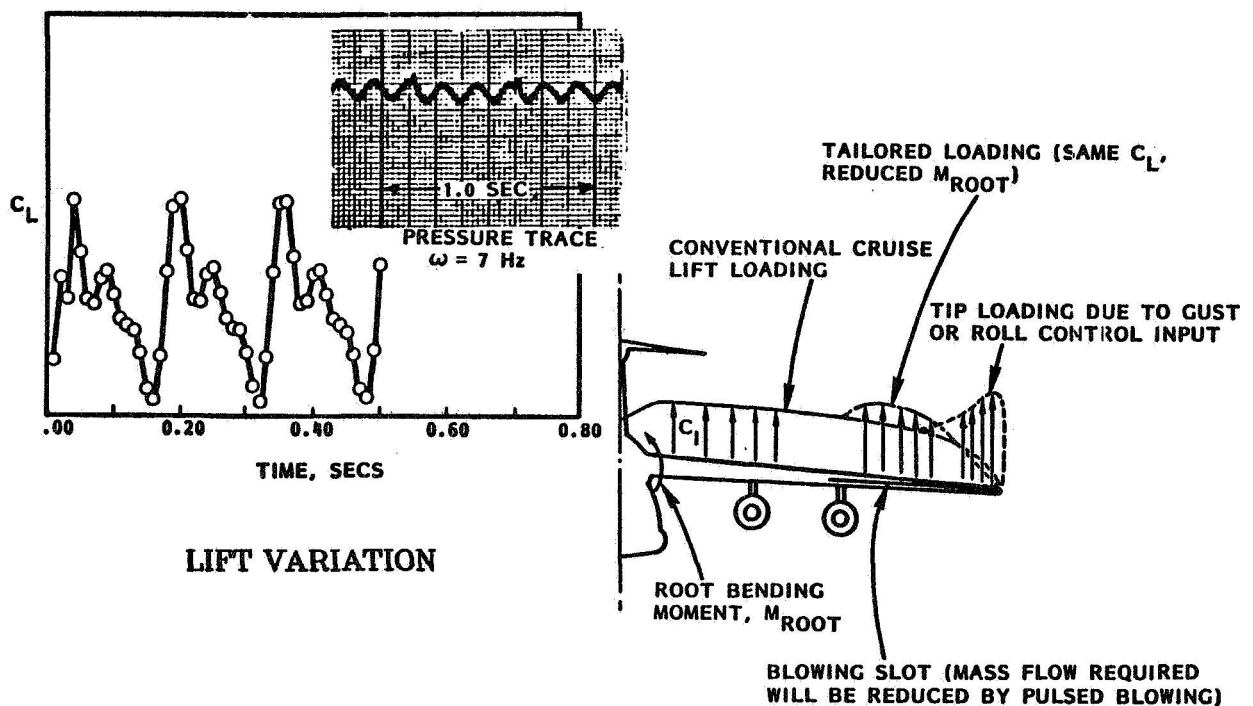
Blown Canard Effect On Generic HSCT Lift and Drag

The generic HSCT model was tested subsonically over a large range of angle of attack for both canards and for several flap configurations on the wing trailing edge. The sketch here shows the locations of both canards relative to the wing leading edge. (Of course, on this half-span model, only one canard was tested at a time). The lower aspect-ratio canard was found to be the more effective of the two, probably because its forward-swept blowing slot aligned the jet sheet more effectively with the wing leading edge and vortex. The lift and drag data shown here are presented for no wing blowing and for a wing $C_{\mu}=0.4$. Also, a 20-degree plain flap was applied to the wing trailing edge, both with and without blowing. The unblown canard provides an increase of approximately 33% in lift and 27% in stall angle over the clean cruise configuration due primarily to delay of wing vortex burst. Addition of blowing to the low-deflection wing flap increases lift by 65% with no change in stall angle. However, the real payoff occurs from adding the blown canard to the blown wing. Here, maximum C_L increases by 103% and the associated stall angle by 29% over the clean configuration. These are improvements achieved without canard deflection. Trimming of the airplane needs to be evaluated by use of both canard and tail deflection (the present wind tunnel model is tailless). An additional advantage from these blown configurations is terminal area operation at much lower angle of attack. The maximum lift $C_L=1.06$ of the clean configuration occurs at $\alpha=24^\circ$, while wing blowing or canard presence achieves that same C_L at $\alpha=8^\circ$. Significant drag reduction is also possible. At the maximum lift of the clean configuration, wing blowing alone ($C_{\mu}=0.4$) reduces the drag from $C_D=0.56$ to 0.02. This is a combination of blowing thrust recovery and lower aircraft angle of attack. At that same drag value for the clean configuration, the lift can be increased from $C_L=1.06$ to 1.8 (67%) by use of wing and canard blowing. Conceivably, adjustment of canard and wing blowing could optimized L/D values for both takeoff and landing.



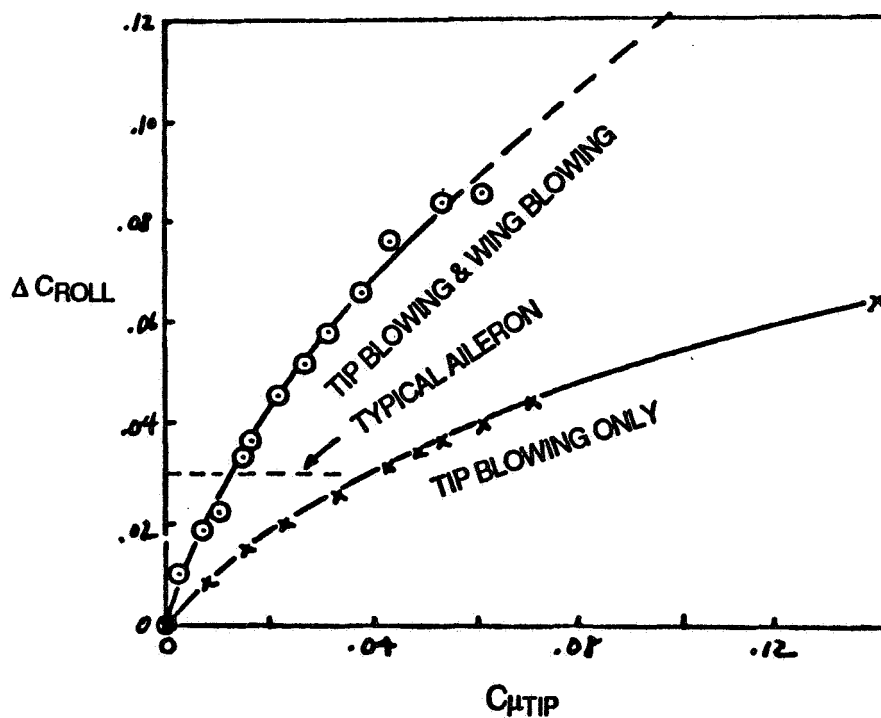
Cyclic Blowing and Load Tailoring

Additional opportunities exist for pneumatic lift and control of both low-speed and high-speed transports. It has been shown during earlier pneumatic applications to helicopters that pneumatic blowing could be made to vary quite rapidly (30 cycles per second or more). Recent applications to fixed-wing aircraft show additional benefits. From a control standpoint, aerodynamic response at 30 cycles per second is quite beneficial. We have also found that cyclic blowing can reduce the amount of mass flow required from the engine to augment aerodynamic forces. For instance, a time-averaged lift can be obtained at an average mass flow which is less than the constant mass flow value required for the same lift under steady-state conditions. From a controls standpoint, it is also possible to pneumatically tailor both the spanwise lift loading (and thus the induced drag) as well as the lifting surface root bending moments. It is possible to provide an elliptic spanwise slot distribution and thus an elliptic lift distribution with the associated minimum induced drag. It is also possible to reduce tip loadings due to gusts by adjustment of blowing values near the wing tip.



CC Wing For Roll Control And Drag Reduction

Pneumatic treatment at the wing tips can provide significant returns from both an aerodynamic and a safety-of-flight standpoint. By use of a proprietary blowing geometry at the wing tip, it is possible to induce a flowfield exactly opposite to that generated by a typical wing tip vortex. This blown flowfield offsets and neutralizes the conventional tip vortex, whose strength would otherwise increase proportionately with wing lift. Measured drag on a rectangular planform wing with this pneumatic tip has shown drag reductions up to 14%, which effectively results from an effective increased aspect ratio of the wing. This additional loading of the tip can be used as a roll control device. The data below show that tip blowing alone can double the incremental roll obtained from a typical mechanical aileron. It is also possible to combine tip blowing and asymmetric wing blowing to produce greater lift asymmetries and incremental roll, increasing roll by up to four times that obtainable from an aileron.



Challenge to American Aerospace Technology

The American commercial aircraft industry is under challenge from foreign competitors in terms of both Advanced Subsonic Transports (AST) and the High Speed Civil Transport (HSCT). For example, during its first commercial flight in June 1995, the latest Boeing airliner, the 777, was already competing against two similar foreign aircraft, the A330 and A340 (by the European consortium Airbus Industrie including member companies from Britain, France, Germany and Spain). The American MD-11 aircraft faces similar competition. US airlines are already buying and flying a number of these foreign-built aircraft (see below). American industry has yet to produce even a prototype HSCT, but the British/French consortium built the Concorde supersonic transport which has been flying commercially (with flights into the US) since 1976. *American advanced transport technology is behind.* Even though numerous research programs have been conducted over the years and promising technology developed, a concentrated efficient integration of these technologies (including thorough environmental and economic impact analyses) has not been completed. The next generation of efficient commercial aircraft must exhibit superior performance; satisfy all noise and environmental requirements; and exhibit adequate economic potential by satisfying the interests of airlines and by offering an affordable ticket price to the passenger. In order to achieve all these objectives, the designer must, early in the design process, account for cost of operation and reliability/maintainability. State-of-the-art aerodynamic, propulsive, control, noise, and operational technologies need to be developed, and a logical means to effectively integrate these into promising advanced US designs needs to be employed. Advances in pneumatic technology and its application to American transport designs can yield major benefits to our industry.

Valujet nearing purchase of new jets

Airbus A319 is
insider favorite

(Atlanta Journal-Constitution, 9/20/95)

By Rodney Ho
STAFF WRITER

Northwest Airlines Airbus A320



Application Towards Efficient Future Transport Systems

The slide below suggests how the research community might employ the major advantages of pneumatic technology to enhance a number of the advanced transport configurations being discussed in this NASA workshop. The main emphasis should be placed on developing an aerodynamic/propulsive force and control system taking maximum benefit from the force/moment augmentations possible from these advanced no-moving-part pneumatic systems at low blowing rates. Clever integration of this technology can provide a simple, reliable efficient aircraft able to adjust its configuration pneumatically to optimize it for each particular phase of flight.

Application Towards Efficient Future Transport Systems

- **Integrated Force Generation , Control Surface, Safety of Flight & Performance Optimization Systems**
- **Integrated Aero/Propulsive/Stability & Control on Advanced Simple Aircraft**
- **Safety of Flight - Wave Vortex**
Microburst/Wind Shear
 α - Independence
Very Low Flight Speed
- **Terminal Area Operations : Noise Reductions (Footprint, Airframe)**
: Improved Gross Weight and Payload
: Reduced Flight Speeds & Take Off/Landing Distances
- **Very Large Transport : Gross Weight Increase, Terminal Area Downsize**
- **HSCT - Wing & Control System Integration; Not α - dependent; Noise Reduction**
- **Lift/Control on Unique Configurations:** Blended Wing Body
Oblique Wing
Corporate-Supersonic Transport
Rotary Wing (Simplicity; efficiency; max speed)

What's Needed??

Proof of concept verification of much of this pneumatic technology has already occurred, and patents exist or have been applied for. Immediate research and systems analysis that need to be accomplished near-term are shown below. Applications to near-term designs such as the Advanced Subsonic Transport and the High Speed Civil Transport should take precedence. Integration of aerodynamic, propulsion, stability & control, and acoustics teams into a unified design effort is essential.

WHAT'S NEEDED??

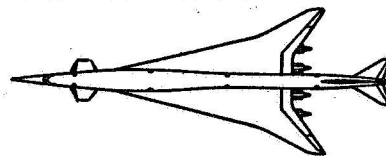
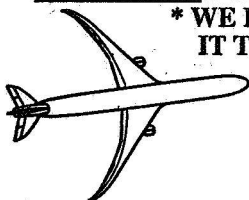
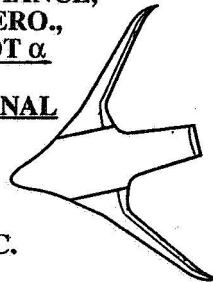
- **High Speed Performance of Pneumatic Airfoils**
- **Mission Integration; System Analysis; Payoffs & Penalties; MDO**
- **Experimental /CFD Evaluation for Particular Configurations/Applications**
- **Full-Scale Proof-of-Concept on Subsonic Commercial Transport
Has Already Been Proof-of-Concept Flight-Tested on Military Aircraft**
- **Operations Analysis, New Uses:**
 - **Noise Abatement**
 - **Wing Downsize**
 - **Systems Synergistic Integration**
- **HSCT - Configuration Optimization**

Pneumatic Aerodynamic Technology --- Where Do We Go From Here?

Major efforts to pursue in order to take advantage of this major breakthrough in aerodynamic technology are shown below. Let's apply this pneumatic technology to integrated systems to optimize aircraft design and performance pneumatically, not mechanically. Let's take advantage of an existing research data base and undertake a large-scale effort to apply this technology to near-term aircraft designs. This could motivate the American aircraft industry to include this technology in their designs, before the European and Far East competitors do.

PNEUMATIC AERODYNAMIC TECHNOLOGY --- WHERE DO WE GO FROM HERE?

- **A VIRTUAL BREAKTHROUGH IN MOST AREAS OF AVIATION:**
 - * AERODYNAMICS, PROPULSION, PERFORMANCE,
 - * STABILITY AND CONTROL, UNSTEADY AERO.,
 - * ACOUSTICS, STRUCTURES; BLOWING NOT α
- **OPTIMIZE CC AIRFOIL PERFORMANCE & OPERATIONAL LIMITS:**
 - * LOW & HIGH SPEED
 - * AERODYNAMIC PARAMETERS
 - * GEOMETRIC PARAMETERS
 - * AIR SOURCES, PROPULSION, DUCTING, ETC.
- **SYNERGIZE SYSTEMS:** * COMBINE AERO., PROPULSION, CONTROL, ACOUSTICS, PERFORMANCE, ETC.
* SYNERGISTICALLY INTEGRATE FROM THE OUTSET, NOT AS AN AFTERTHOUGHT
- **OVERCOME POLITICAL/EMOTIONAL AERODYNAMICS:**
 - * WE HAVE A 22+ YEAR DATABASE -- LET'S PUT IT TO GOOD USE!!





THE FUTURE OF VERY LARGE SUBSONIC TRANSPORTS

R. Steven Justice,

Anthony P. Hays, & Ed L. Parrott

Advanced Design

Lockheed Martin Aeronautical Systems

Lockheed Martin

A stylized, handwritten signature in black ink, appearing to read 'A. Hays'.

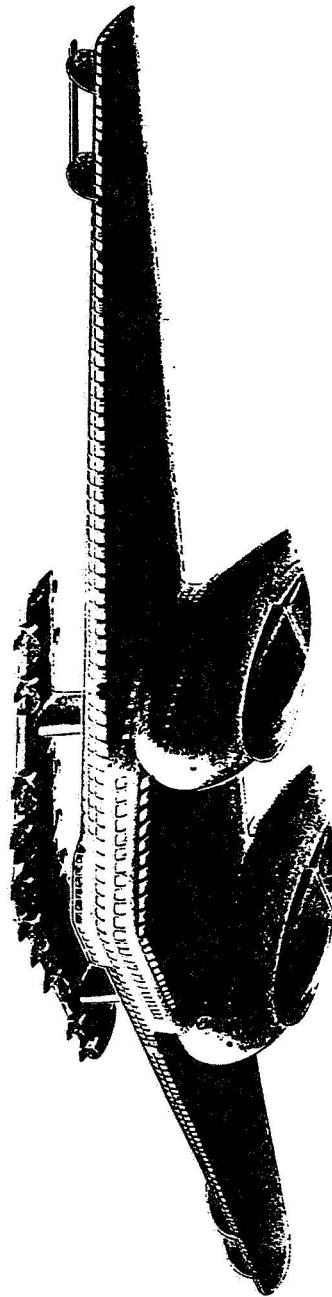
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The Vision

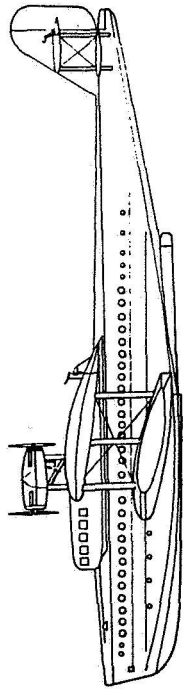
Bel Geddes Air Liner Number 4 (1929)



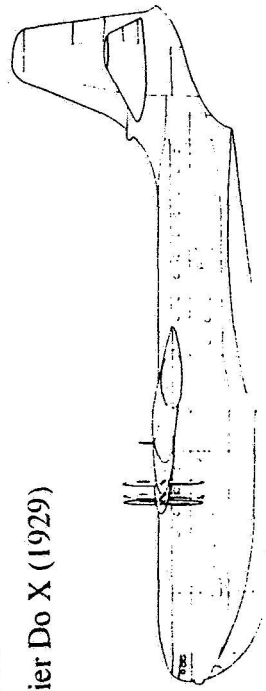

Lockheed Martin



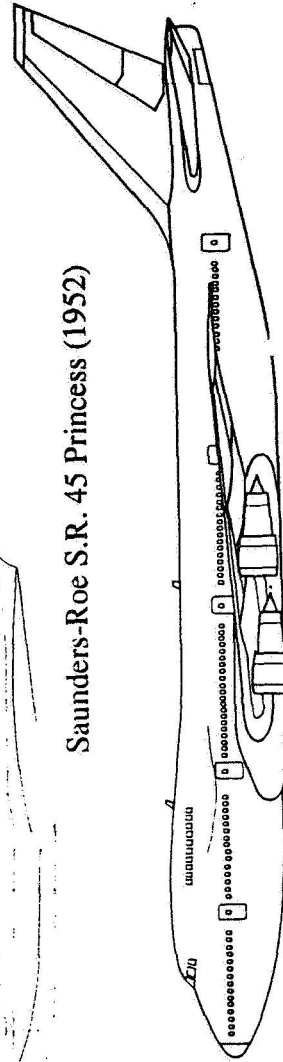
VLST - Past & Present



Dornier Do X (1929)



Saunders-Roe S.R. 45 Princess (1952)



Boeing 747 (1969)





Today's Situation

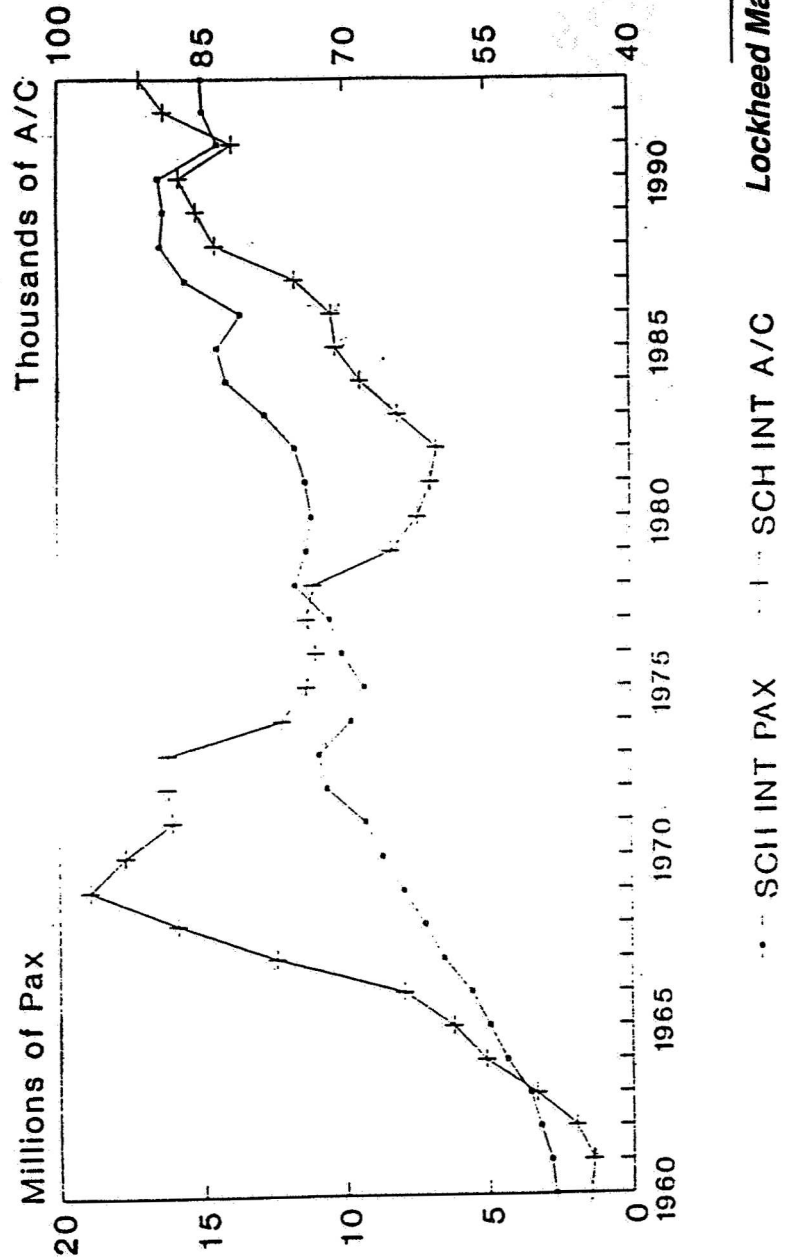
- ◆ Slot Limits At Existing Airports
- ◆ Traffic Growth Outpacing New Airport Development
- ◆ Bigger Aircraft Required To Increase System Capacity & Productivity
- ◆ Heavy Airlift Military Aircraft To Be Replaced In Early 21st Century



Airport Congestion

Kennedy International Airport

International Passengers Vs Aircraft Movements

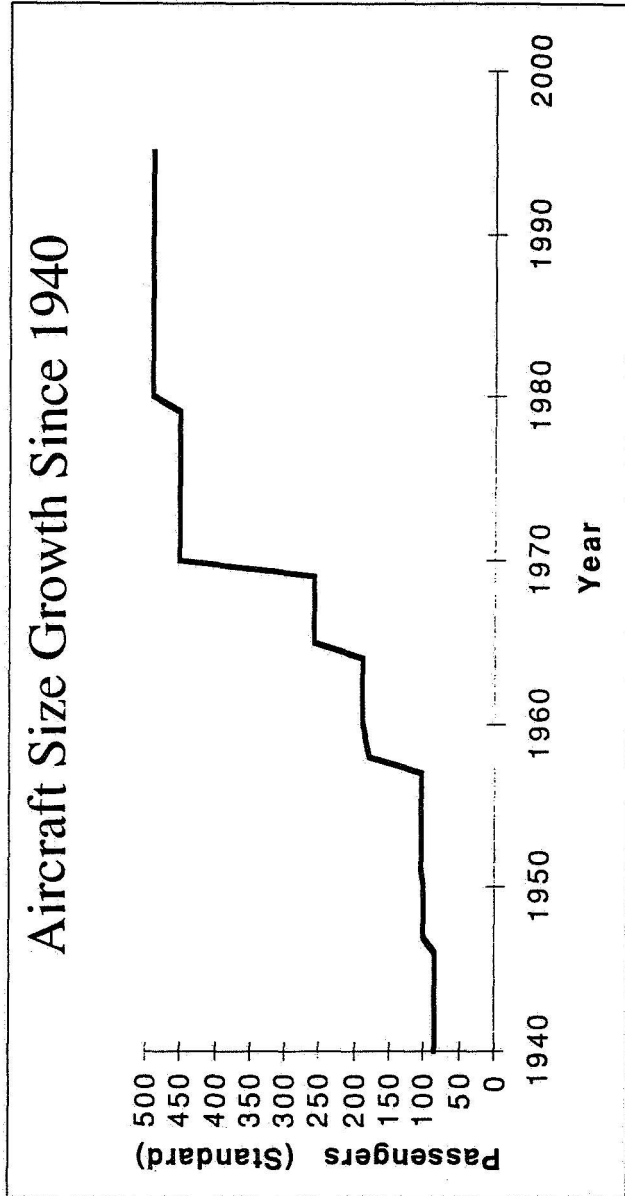


Lockheed Martin



How Did We Get Here?

- ◆ No Significant Increases In Aircraft Capacity Since Early 1970's





VLST Missions

- ◆ Passenger Transport
 - 600 to 800 Passengers Over Global Distances
- ◆ Commercial Freighter
 - 6.5% Annual Cargo Growth
 - Increased Use Of ISO & Intermodal Containers
- ◆ Military Airlift
 - Payload Of C-5 Over Global Distances



Key Design Challenges

- ◆ Size Issues & Constraints
 - Clearances At Gates, Taxiways, & Runways
 - Ground Loading & Flootation
- ◆ Increased Aircraft Separation Requirements
 - Increased Power In Wing Vortex
 - Increased Separation Will Reduce Aircraft Throughput At Airport

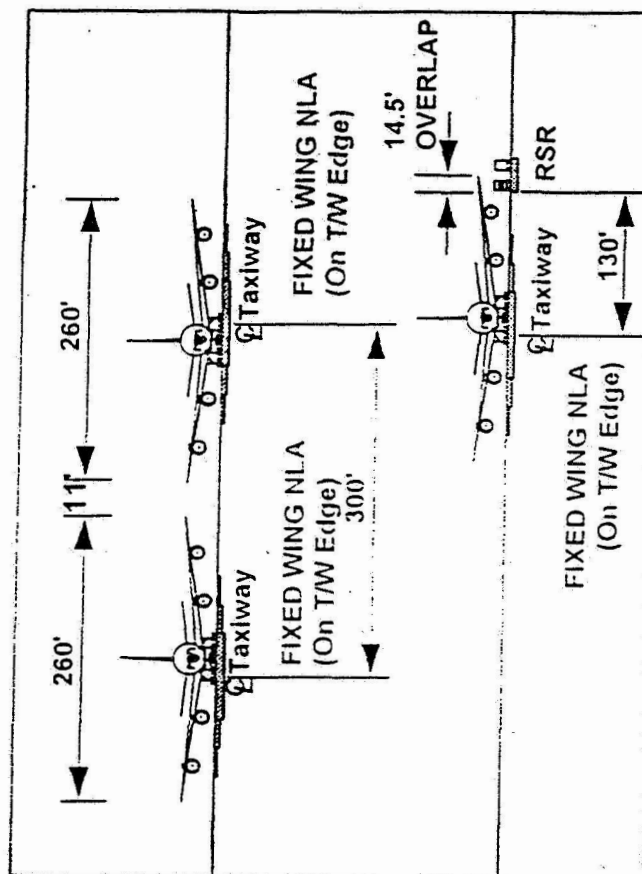
LOCKHEED





Key Design Challenges

◆ Taxiway Clearance



PANY&NJ Aviation Department

Lockheed Martin



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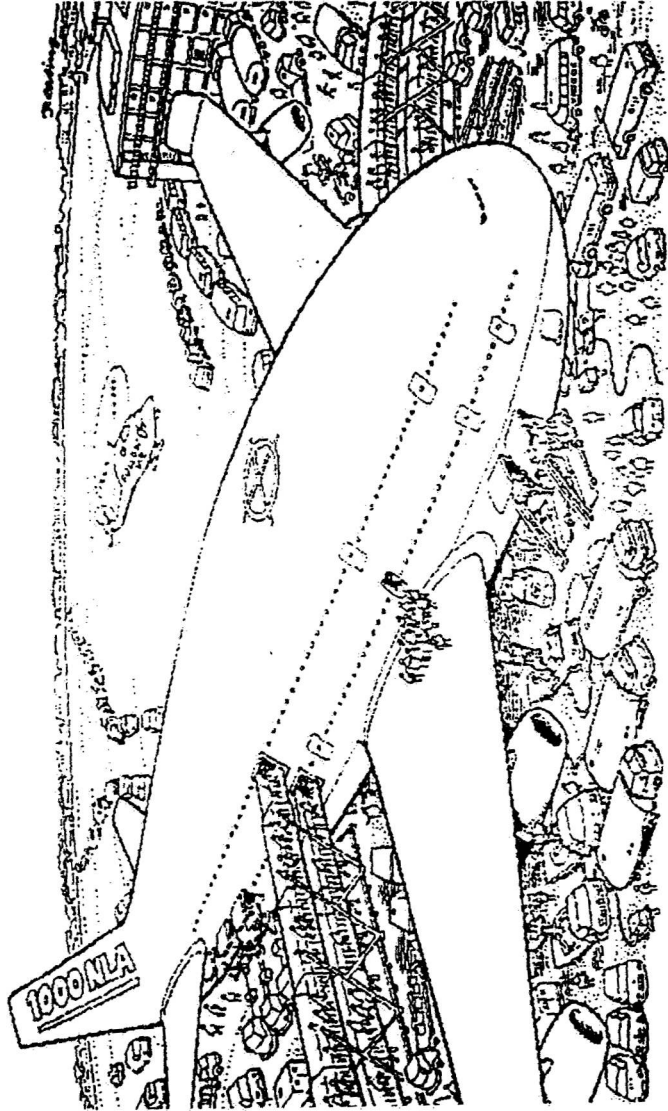
Key Design Challenges

- ◆ Loading & Servicing
 - Compatibility With Current Gates
 - Servicing Vehicle Congestion
 - Longer Time Required For Loading & Servicing



Key Design Challenges

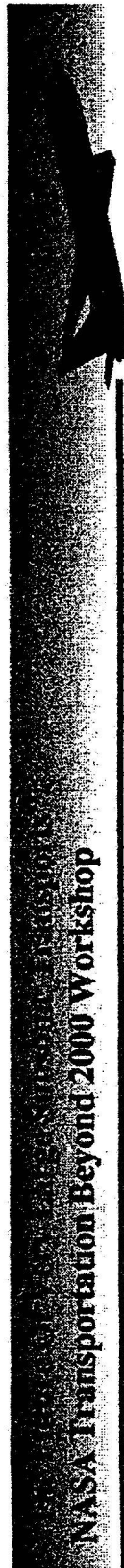
◆ Ground Support



"Airport Support", December 1994

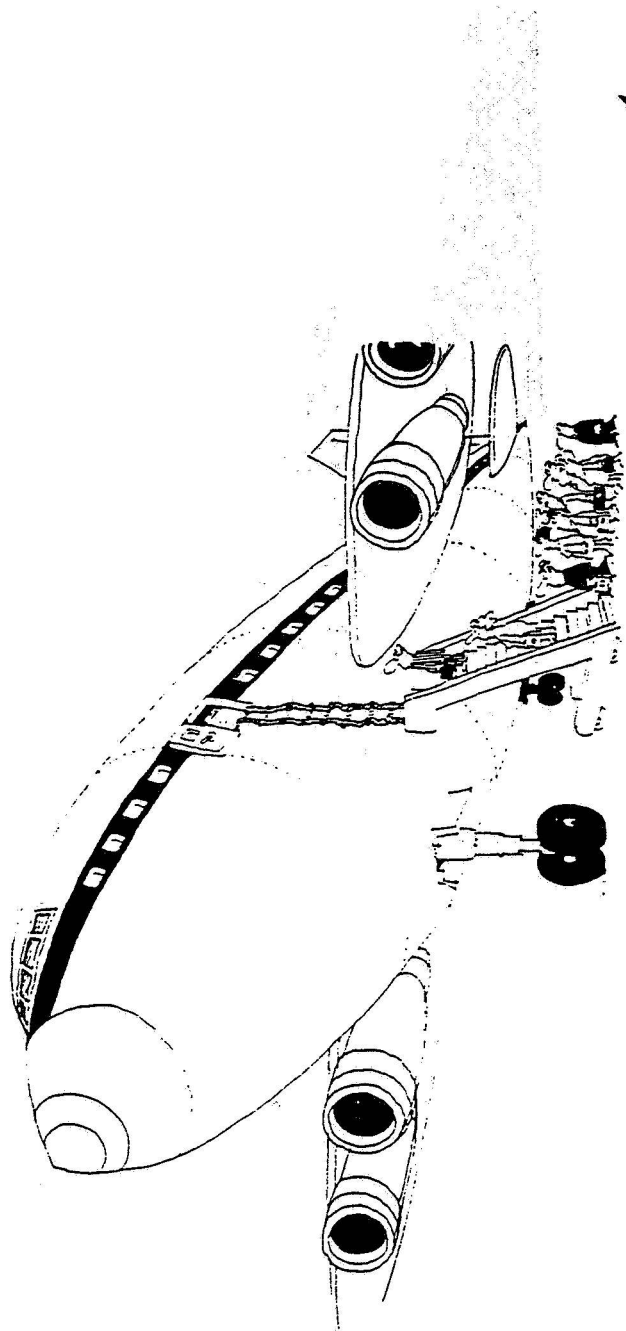
Lockheed Martin





Key Design Challenges

◆ Gate Compatibility



Cartoon copyright © Roland Fuddy, 1994
Copyright © Esley Publications, 1994

Lockheed Martin



Key Design Challenges

- ◆ Emergency Systems
 - Emergency Exit/Slide Height
 - Passenger Escape From Emergency Site
 - Emergency Systems Must Handle Up To 1,600
Victim Event (2 Aircraft)





Key Design Challenges

- ◆ Aircraft Noise Requirements
- ◆ Fabrication Of Large Composite Structures
- ◆ Control Of A Large Flexible Structure

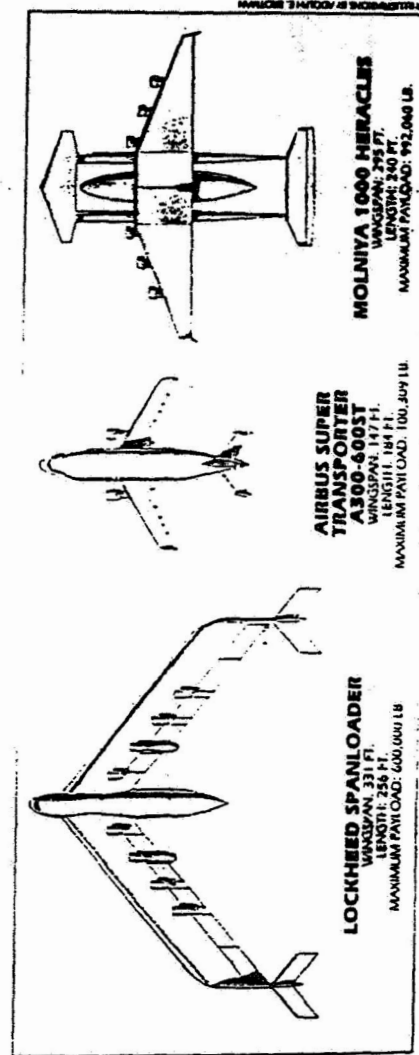
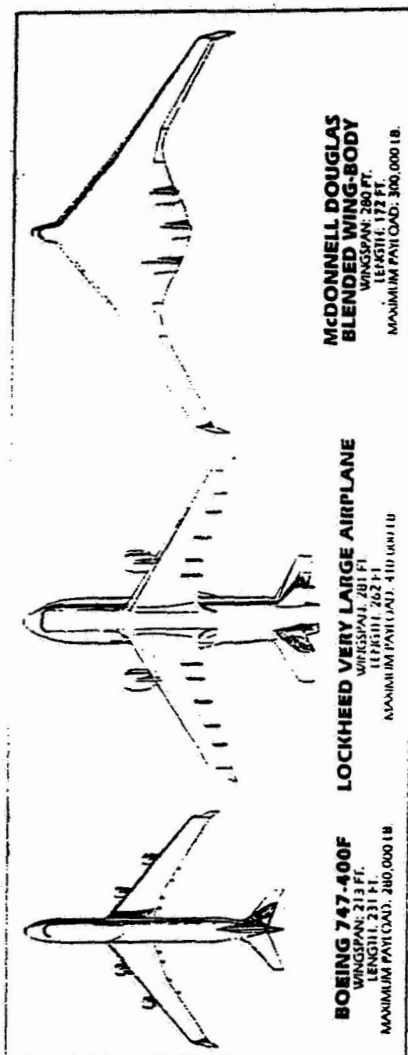


Enabling Technologies

- ◆ Fly-By-Light/Power-By-Wire
- ◆ Active Control Systems
- ◆ Simple, Effective High Lift Systems
- ◆ Laminar Flow (Hybrid & Natural)
- ◆ Flight Deck Systems
- ◆ Modular Design

The Future Of Very Large Subsonic Transports
NASA Transportation Beyond 2000 Workshop

Options For VLST



Lockheed Martin





Options For VLST

- ◆ Sea Based Vehicles
 - Conventional Seaplane
 - Wing In Ground-Effect (WIG)
- ◆ No Runway Construction
- ◆ Use Existing Cargo Port/Terminals
- ◆ Increased Emergency/Alternate Landing Sites

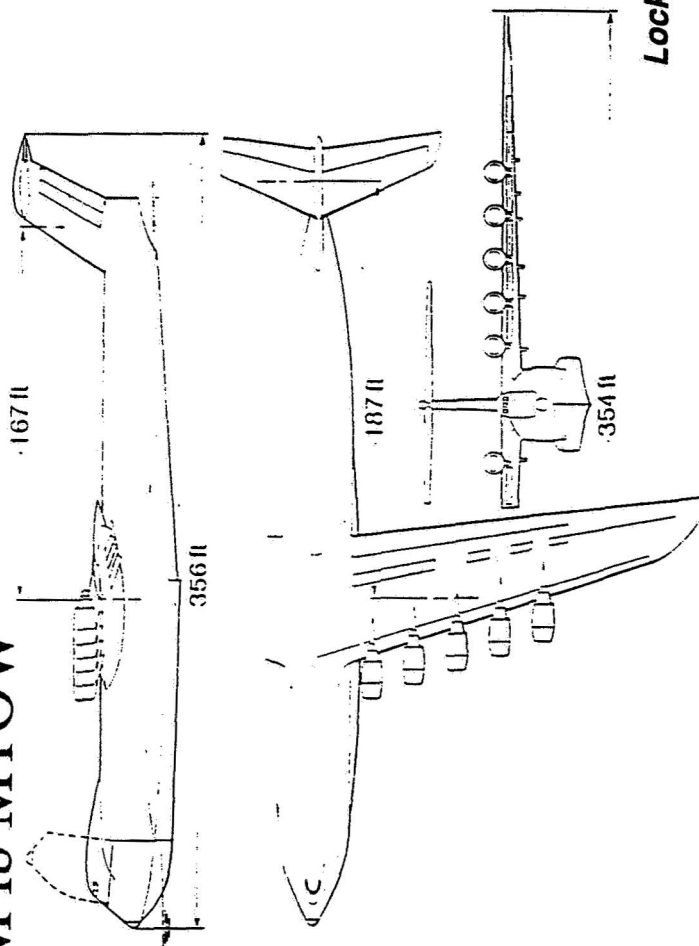

Lockheed Martin

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NASA Transportation Beyond 2000 Workshop



Options For VLST

- ◆ Lockheed/Dornier Sea-Based VLST
 - 3,500 Nm Range With 882k lb Payload
 - 2.2M lb MTOW



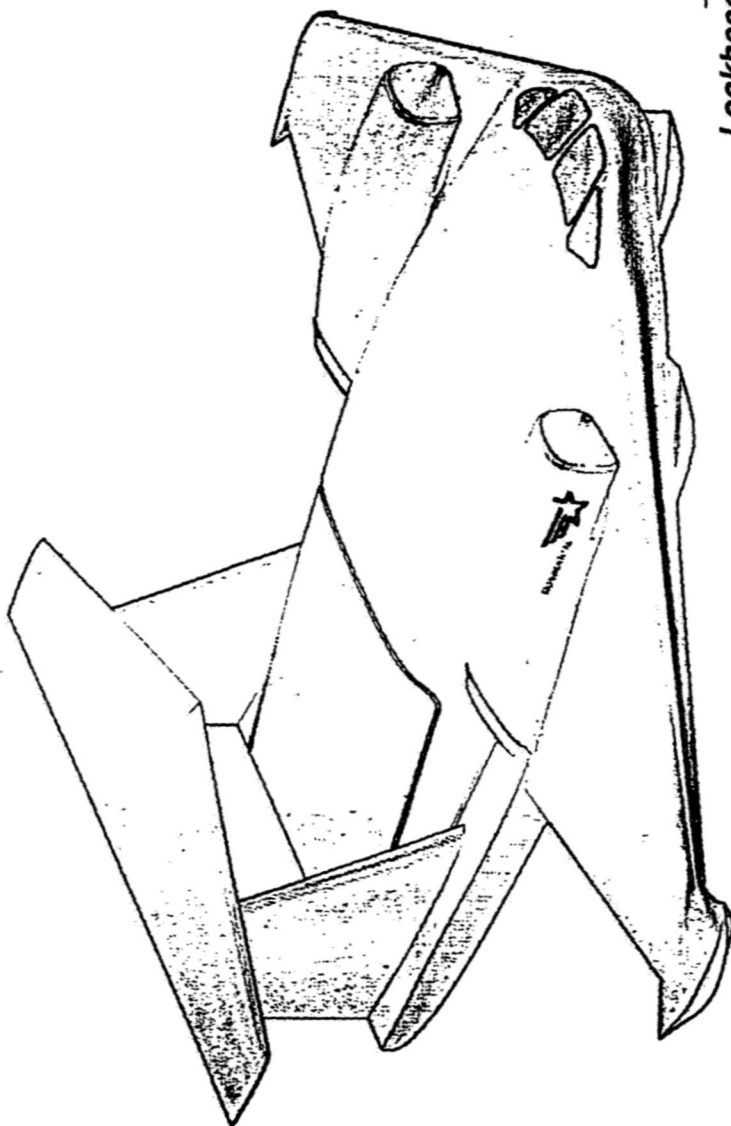
Lockheed Martin





Options For VLST

◆ Lockheed Martin Sea-Based WIG




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Who Will Build The VLST?

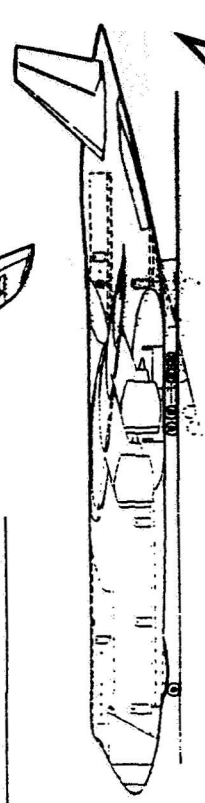
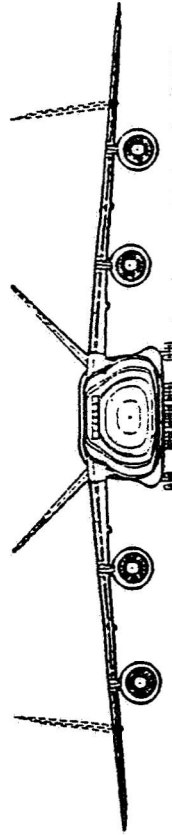
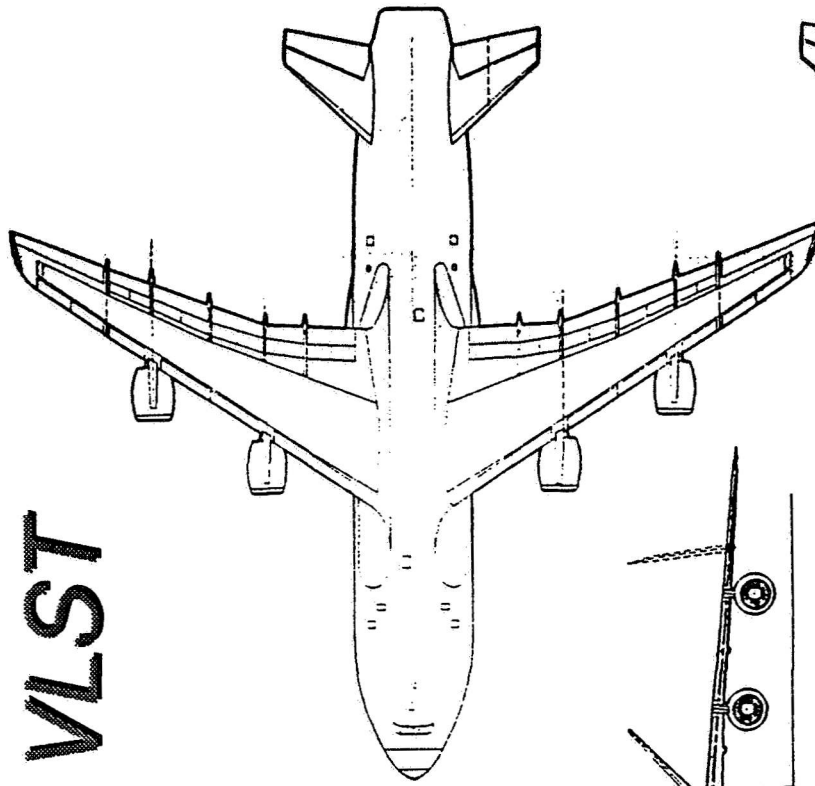
- ◆ McDonnell Douglas
- ◆ Boeing
- ◆ AIRBUS
- ◆ Lockheed Martin





LMAS VLST

- ◆ 1.4 Million Pound Takeoff Weight
- ◆ 282 ft Wing Span (211 ft Folded)
- ◆ 262 ft Length
- ◆ 4 GE90, RR Trent, Or PW4000 Class Engines
- ◆ 3,200 Nm Range With Over 400k lb Payload



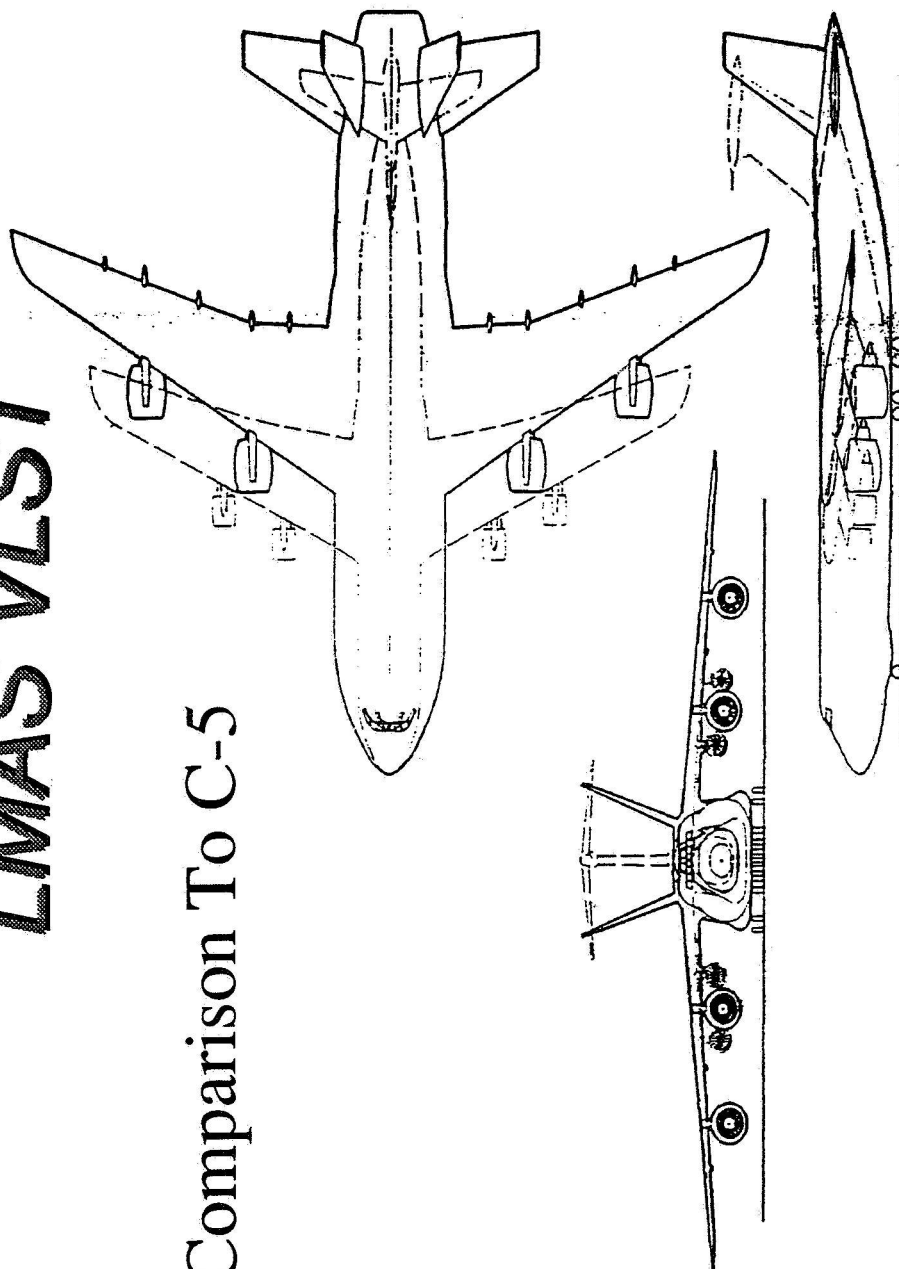
Lockheed Martin

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LMAS VLST

◆ Comparison To C-5



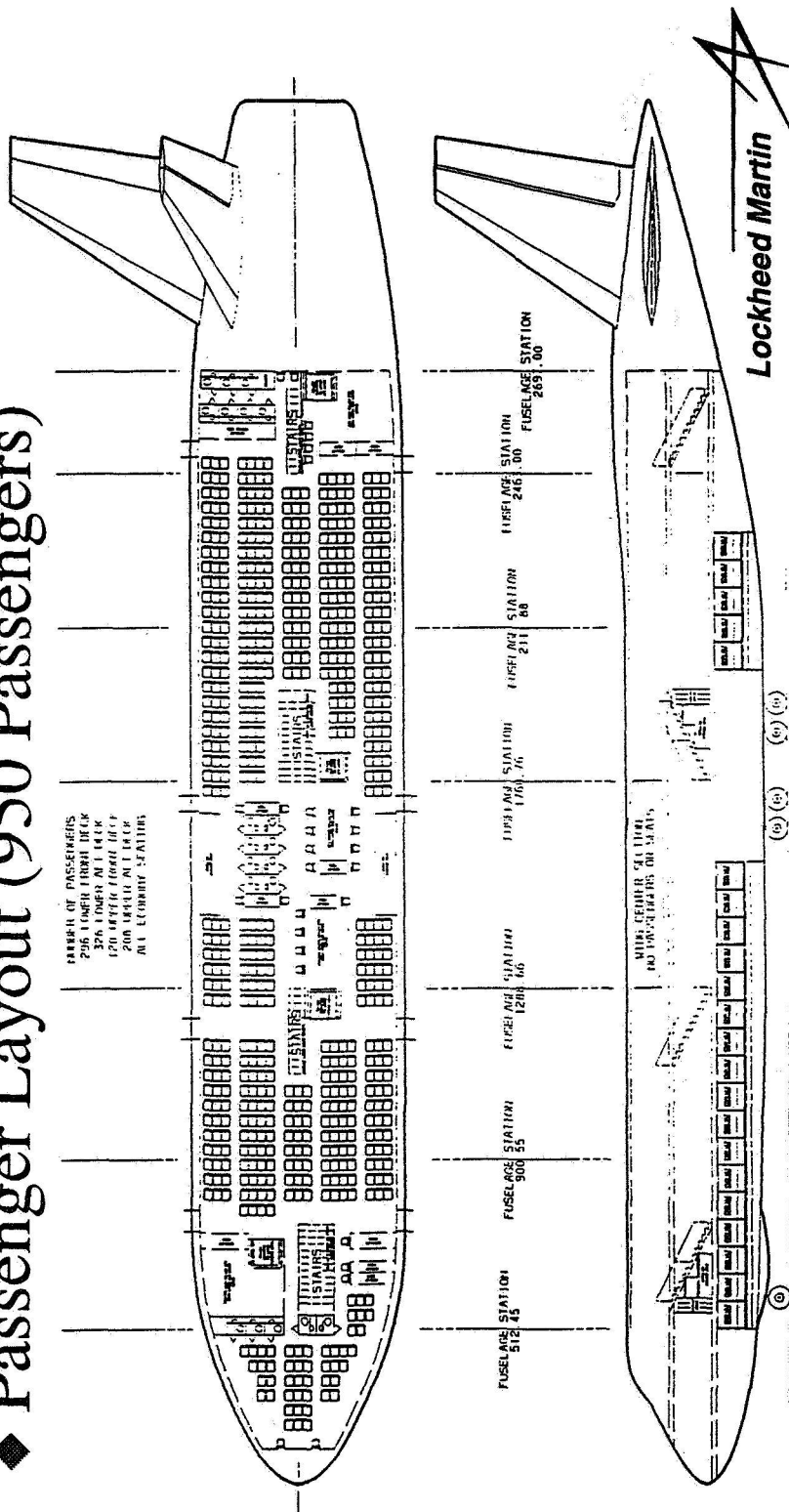
Lockheed Martin





LMAS VLST

◆ Passenger Layout (950 Passengers)

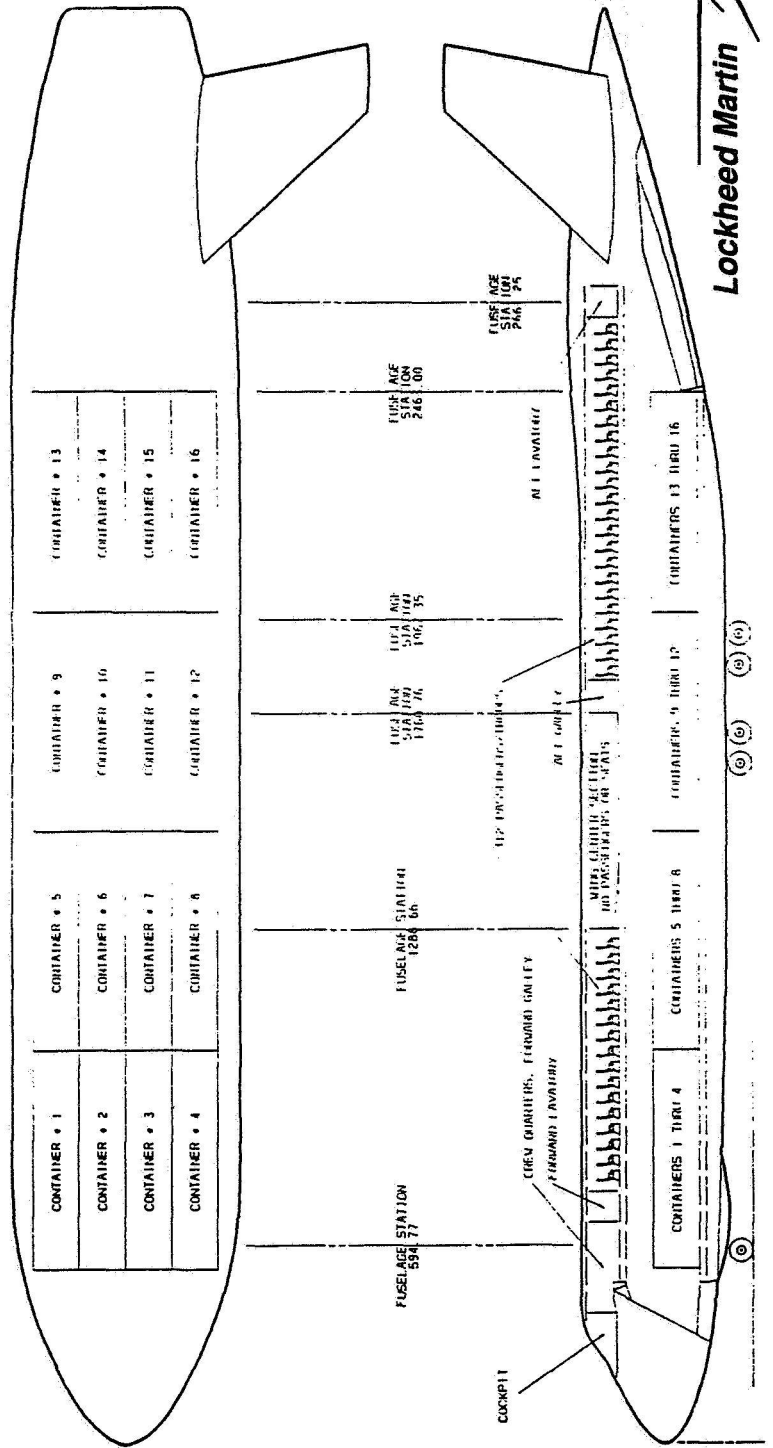


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LMAS VLST

◆ Cargo Layout (16 ISO 40 ft Containers)



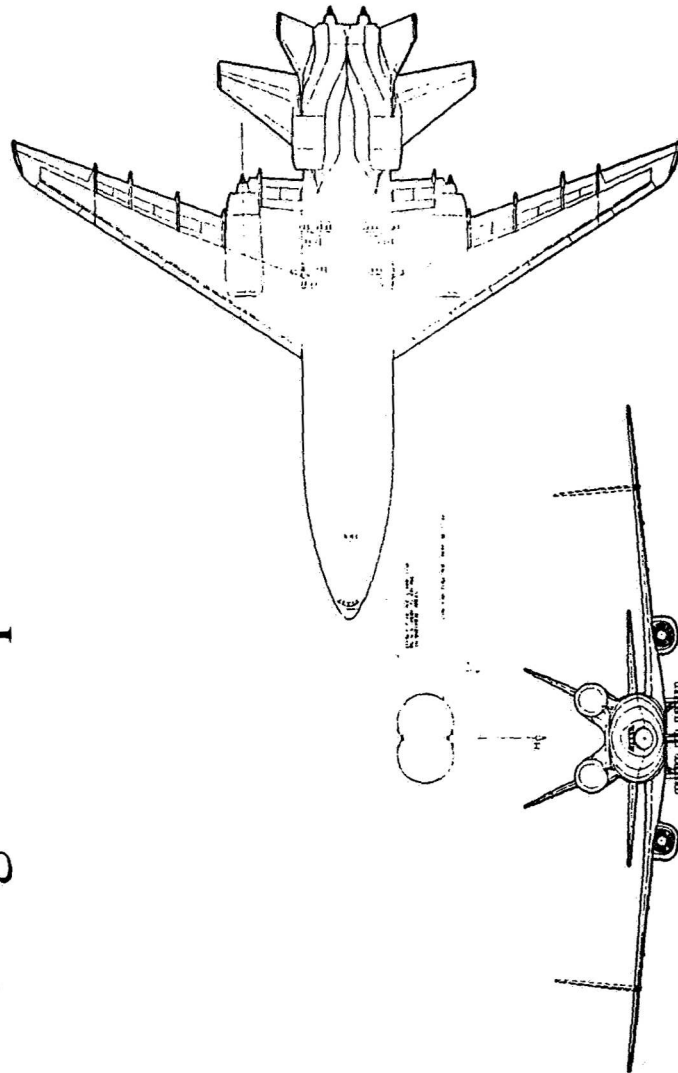
Lockheed Martin

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LMAS VLST

◆ Low Wing Concept

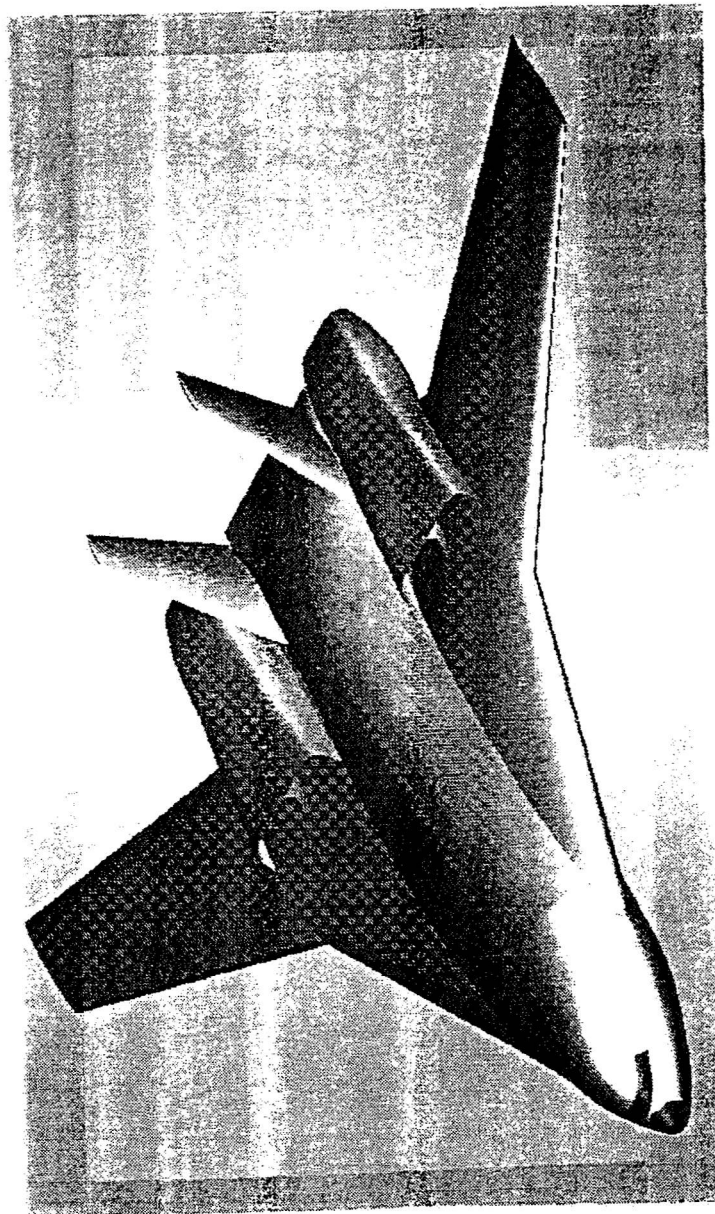


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LMAS VLST

- ◆ Blended Wing/Body Concept

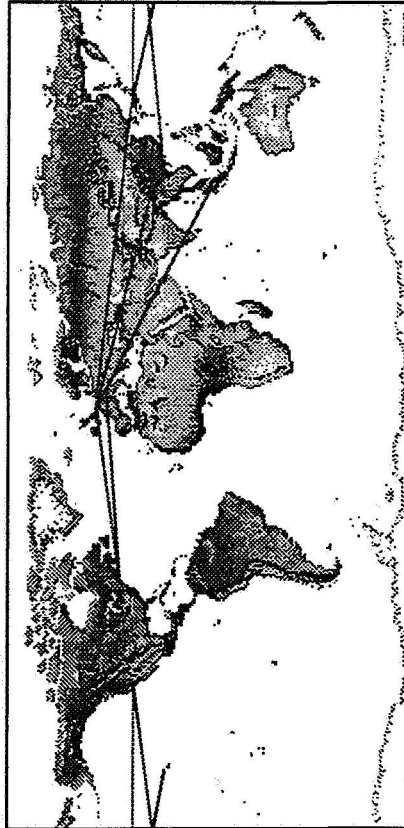



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Routes That Could Use A VLST Today



London - Tokyo
London - Hong Kong
London - Singapore
New York - London
New York - Paris
New York - Frankfurt
Tokyo - San Francisco
Tokyo - Los Angeles
Tokyo - Honolulu
Hong Kong - San Francisco


Lockheed Martin



VLST Market

(By 2010)

◆ Big Enough For More Than One Aircraft?

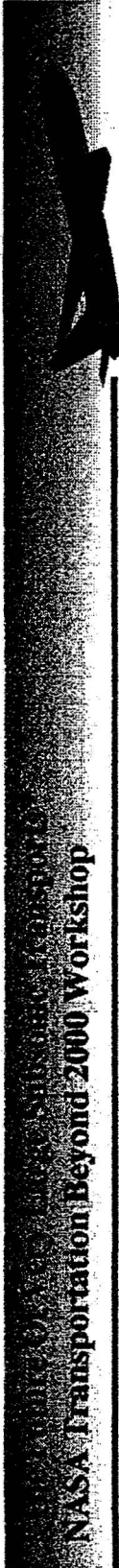
Asia/Pacific	160-200
USA	70-100
Europe	50-70
Total	280-370

(British Airways Forecast)



How Much Money?

- ◆ \$8-15 Billion Development Cost
 - More Than One Company Can Handle
- ◆ \$200-300 Million Unit Cost
 - Larger Than Annual Profits For Many Airlines
 - Unlikely To Be Internally Financed By Airline & Leasing Companies
 - Resulting High Capital Cost For Operator



Summary

- ◆ VLST Is Technically Possible Now
- ◆ Airline Interest Has Decreased Recently
Due To Financial Difficulties
- ◆ Major Aircraft Manufacturers Are Poised
To Act Once Economics Improve



VLST - Argosies Of The Sky!

"For I dipt into the future, far as the human eye could see,
Saw the Vision of the world, and the wonder that would be;
Saw the heavens fill with commerce, argosies of magic sails,
Pilots of the purple twilight, dropping down with costly bales."

Lord Tennyson


Lockheed Martin

Evolution of the Revolutionary Blended-Wing-Body

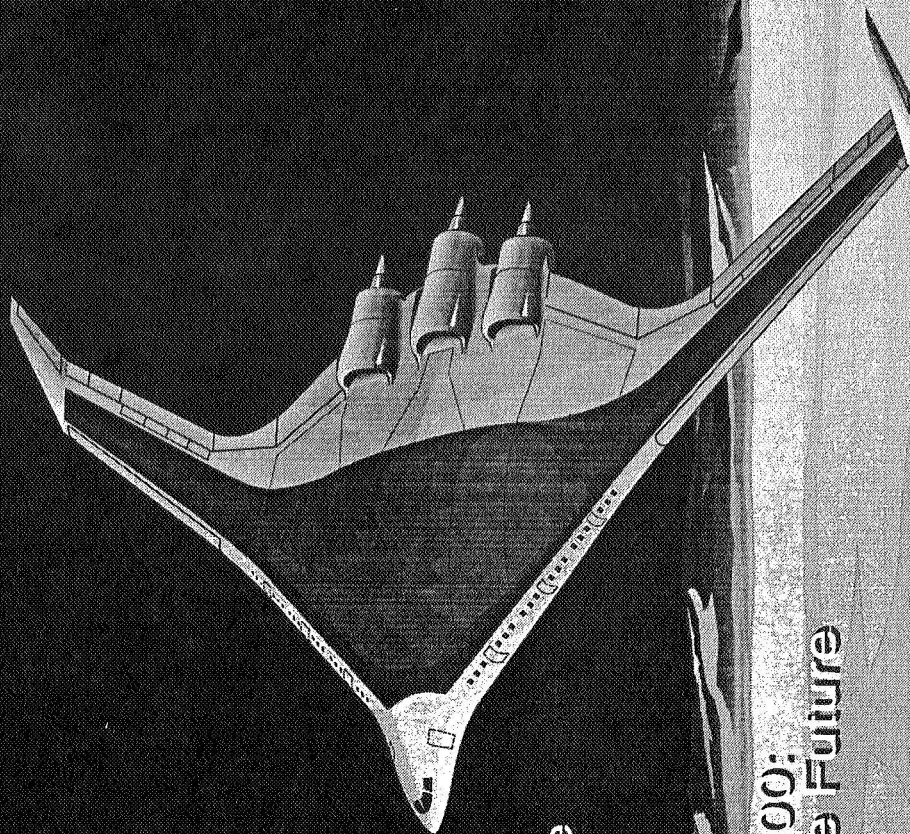
BWB

Robert H. Liebeck
Mark A. Page
Blaine K. Rawdon

McDonnell Douglas Aerospace
Long Beach California

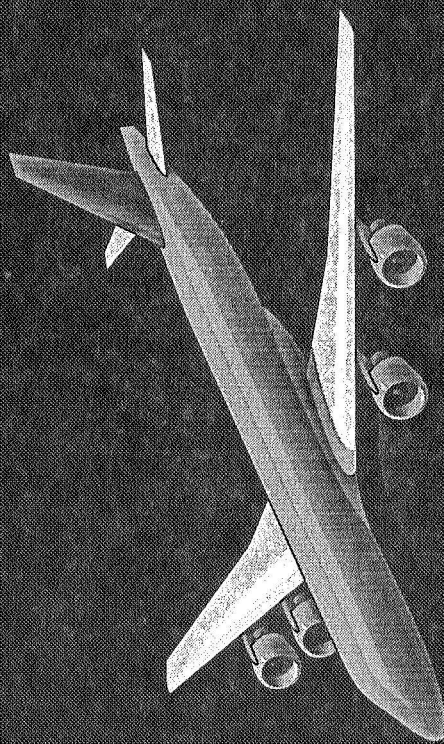
**Transportation Beyond 2000:
Engineering Design for the Future**

NASA Langley Research Center, September 26-28, 1995



315-05
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NASA Question.....

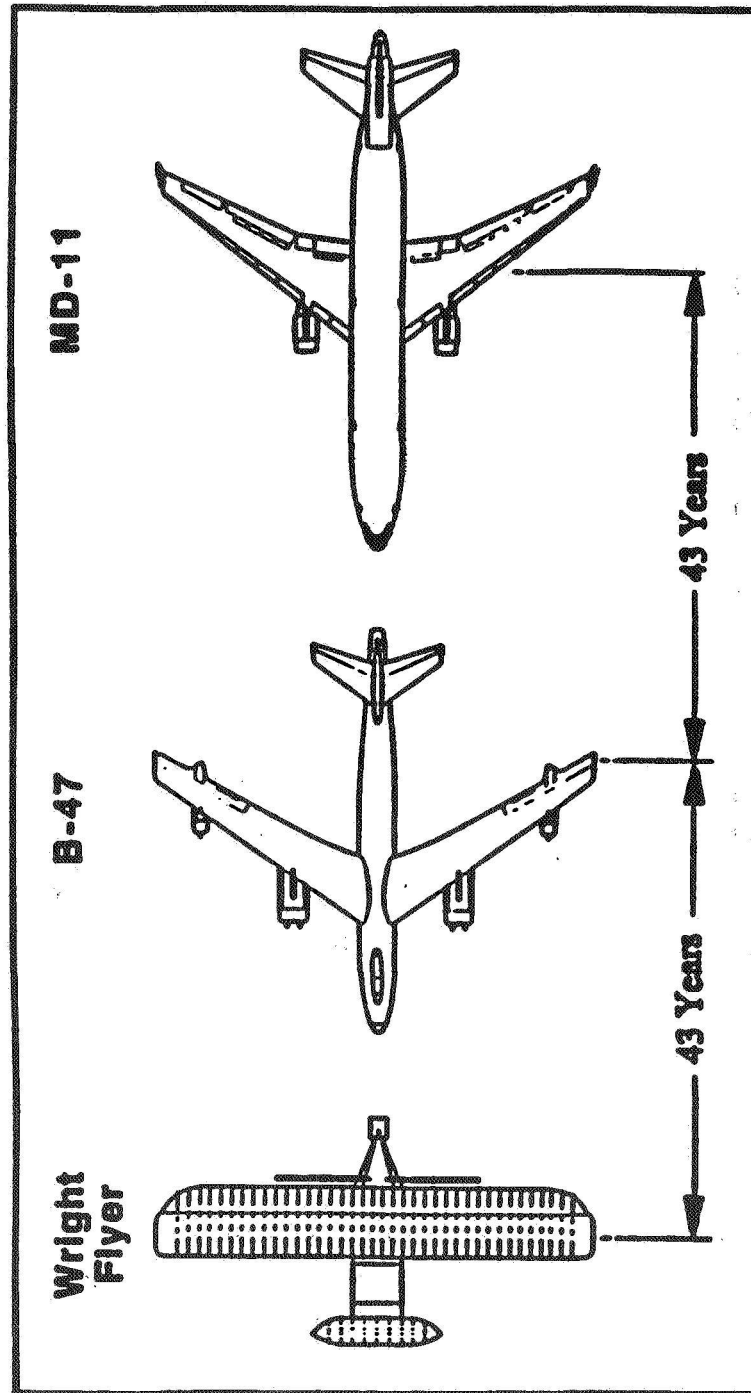


Is There an Aerodynamic Renaissance for the Long-Haul Transport?

- Dennis Bushnell, December 1988

McDonnell Douglas

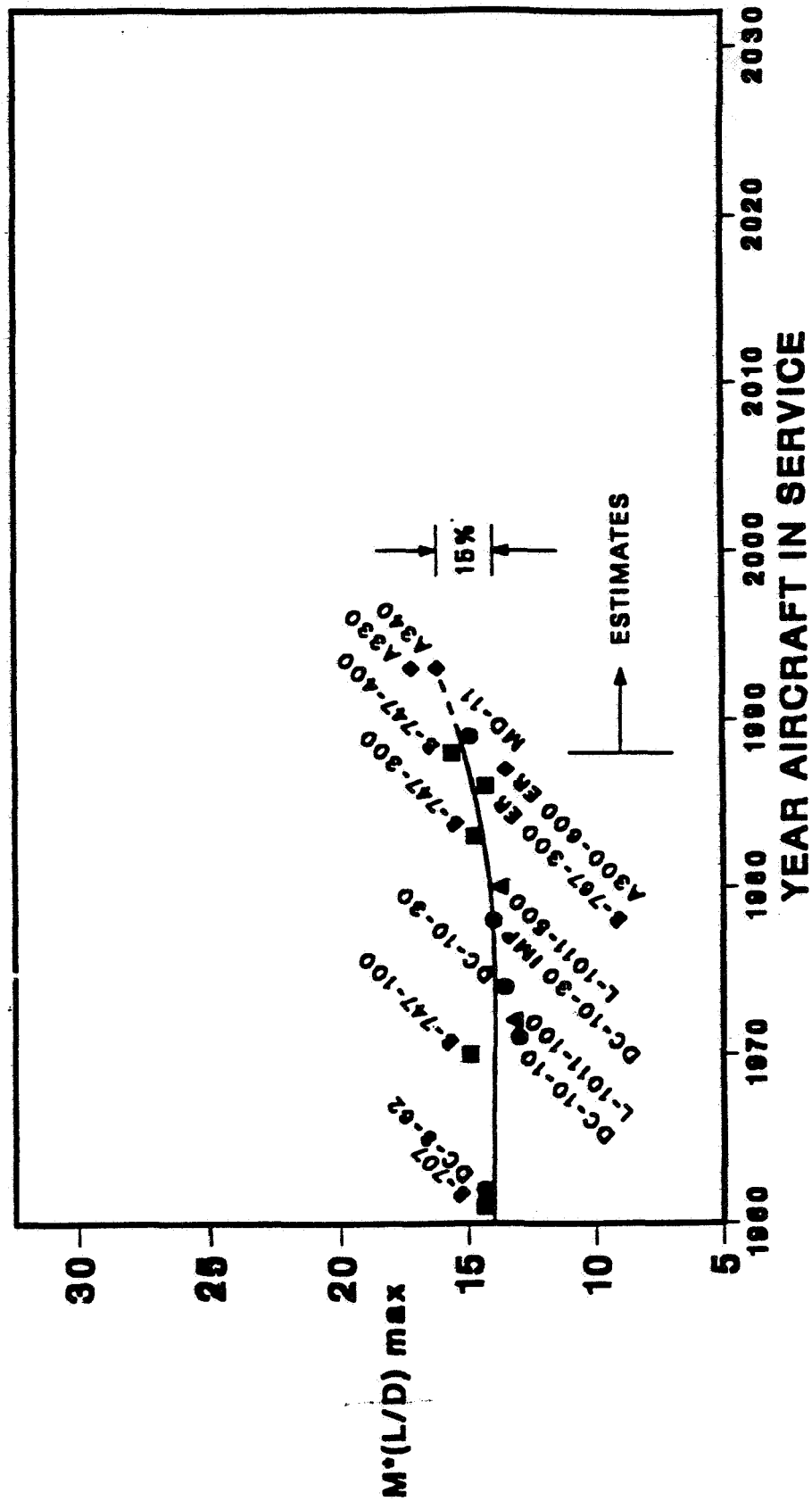
Transport Evolution; the First and Second 43 Years



McDonnell Douglas

AERODYNAMIC EFFICIENCY EVOLUTION OF LONG HAUL COMMERCIAL TRANSPORTS

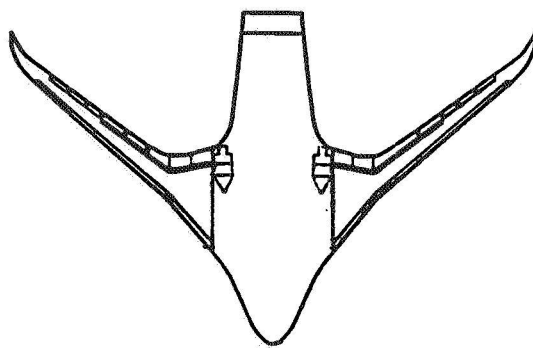
RANGE ≥ 4500 N MI



First Generation BWB

368 Passengers
8,500 nmi Range

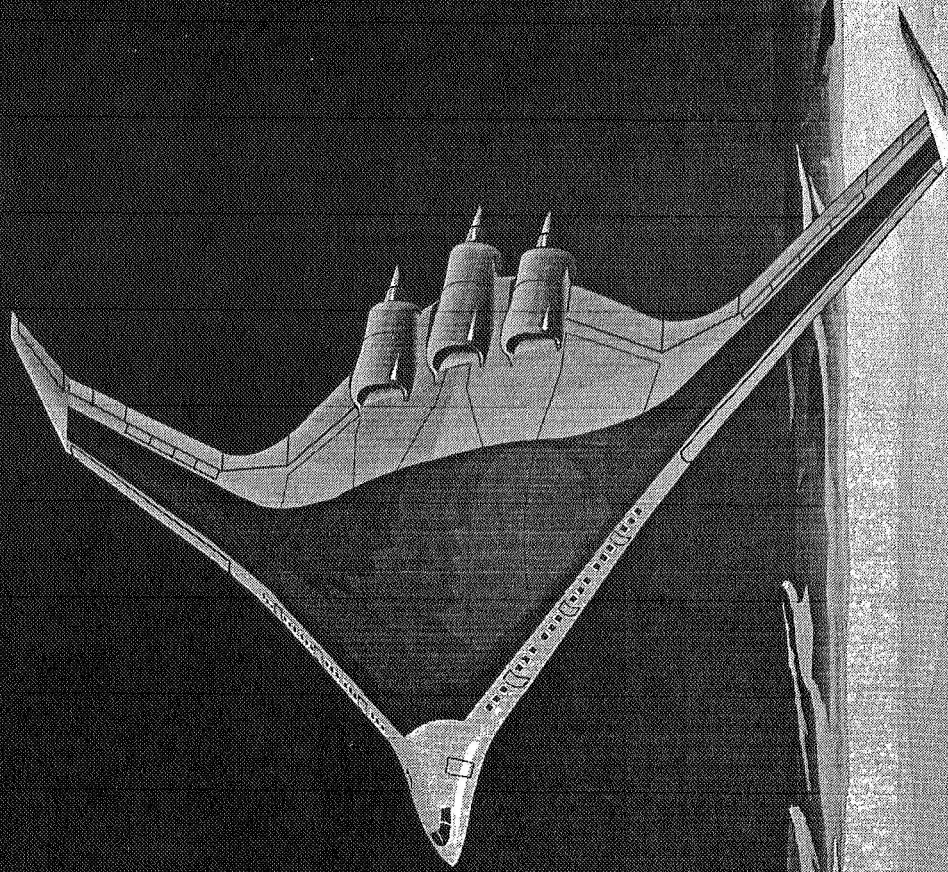
Wing AR = 15.0
Wing Area = 4,500 sq-ft
Wingspan = 259.8 ft
Length = 167 ft



McDonnell Douglas

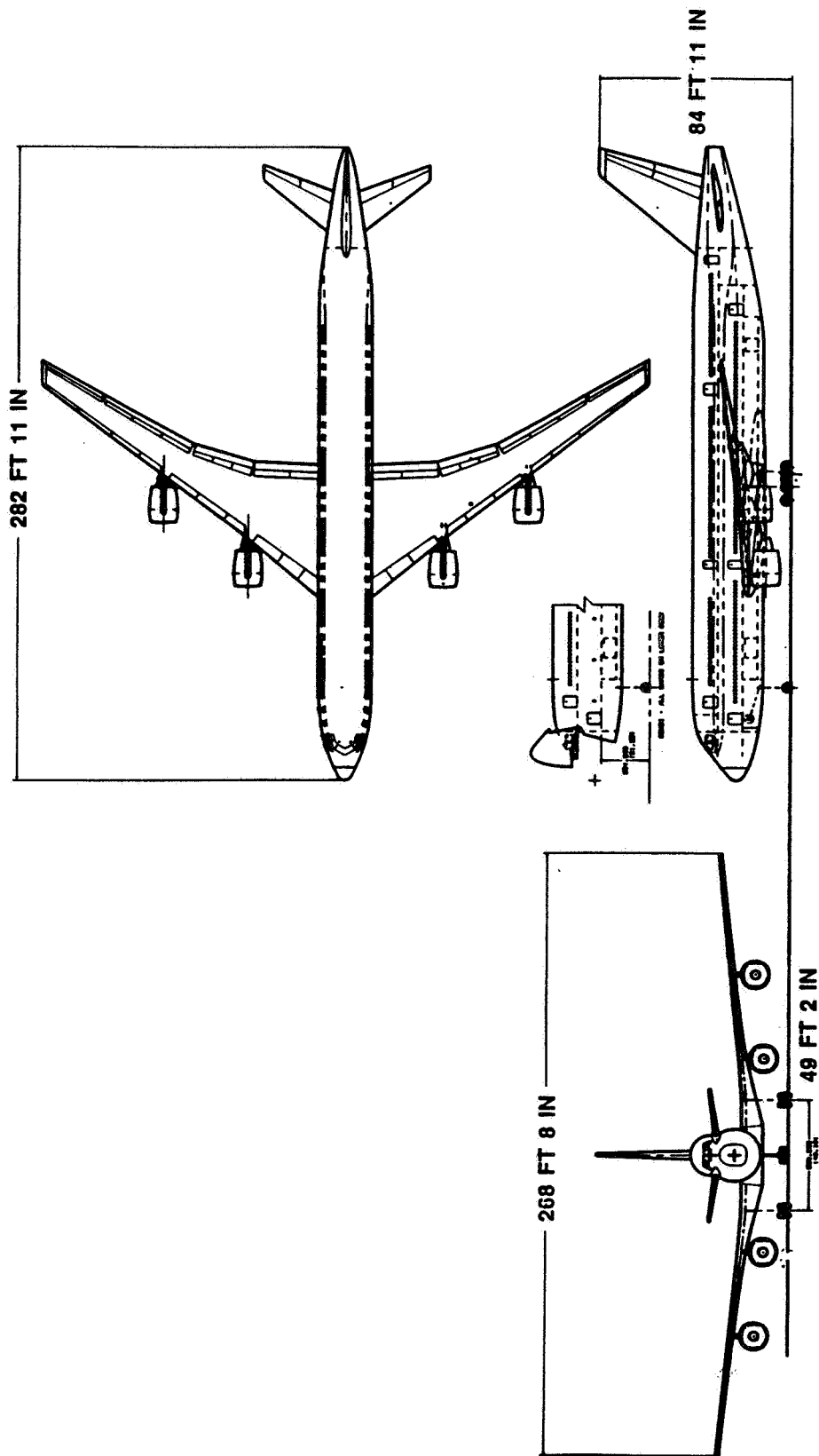
BWB Mission

800 Passengers, 3-class
7,000 nmi Range
Mcrz = 0.85, 35,000 ft min ICA
11,000 ft TOFL
150 Kt Approach Speed
2015 Technology Level
2020 Entry Into Service
ADP Engine Technology
Stitched RFI Structures



McDonnell Douglas

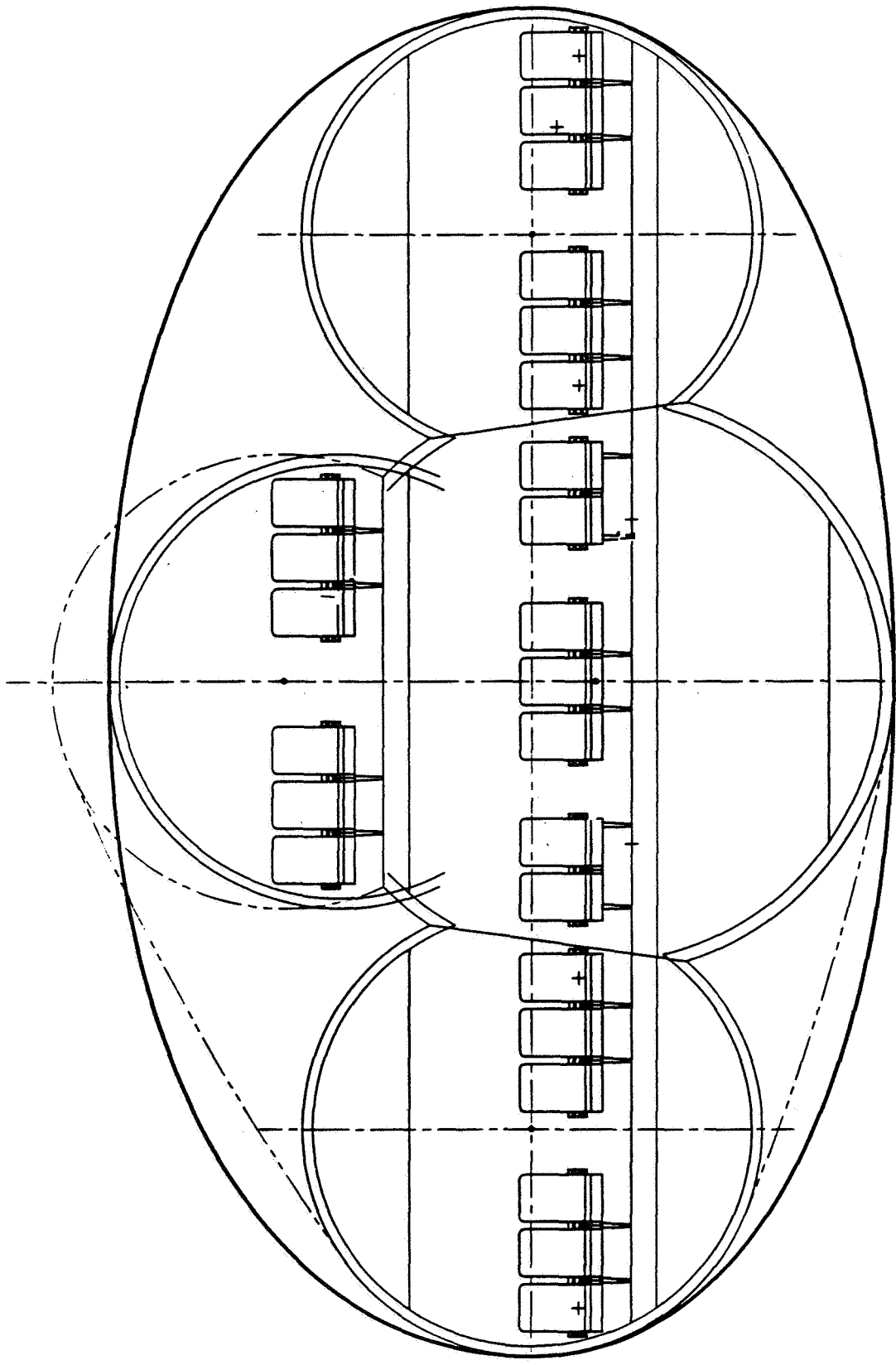
CONVENTIONAL



McDonnell Douglas

BLENDING WING - FIRST ITERATION

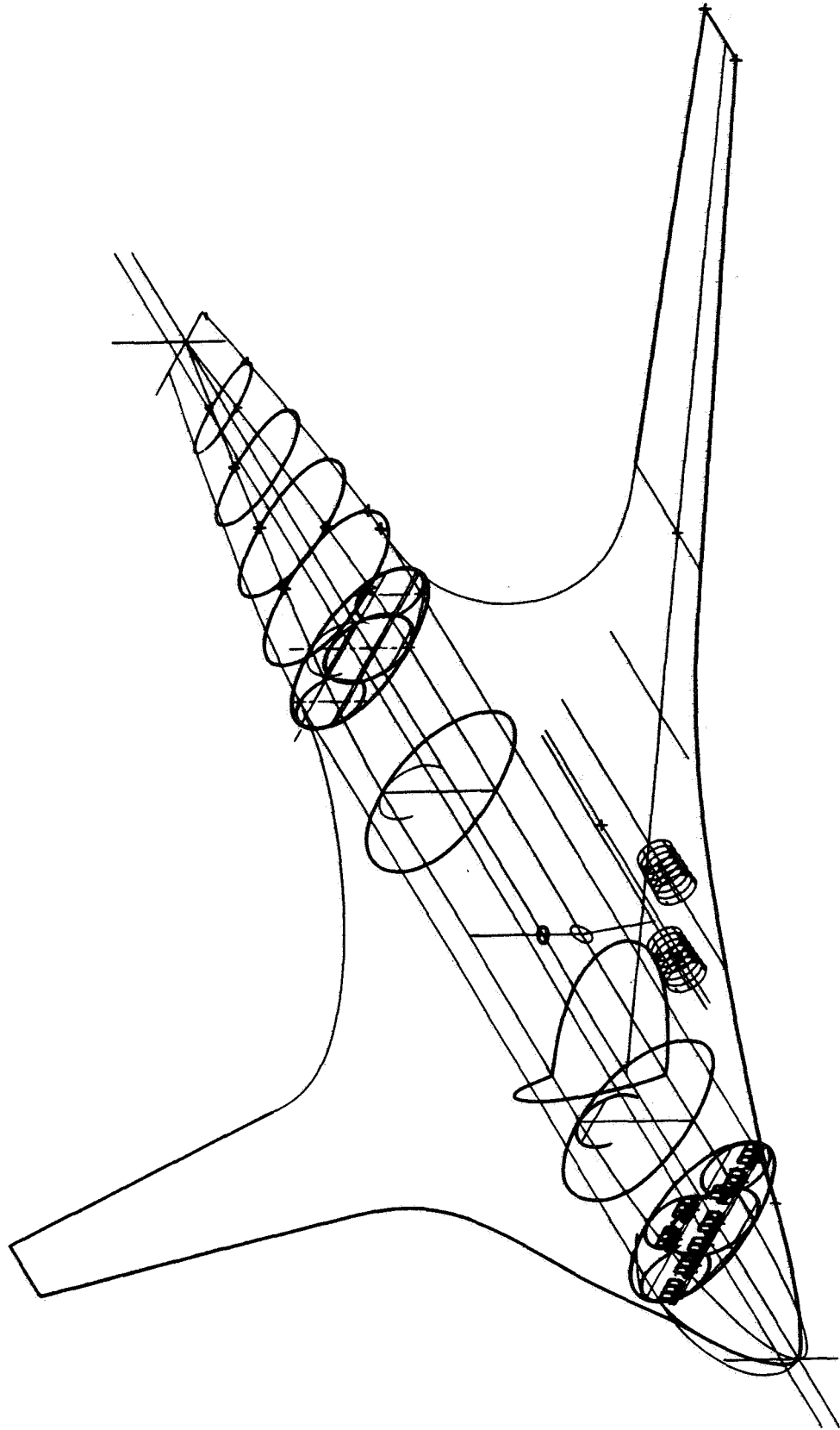
CROSS SECTION - 25 SEATS PER ROW



McDonnell Douglas

BLENDING WING - FIRST ITERATION

ISOMETRIC

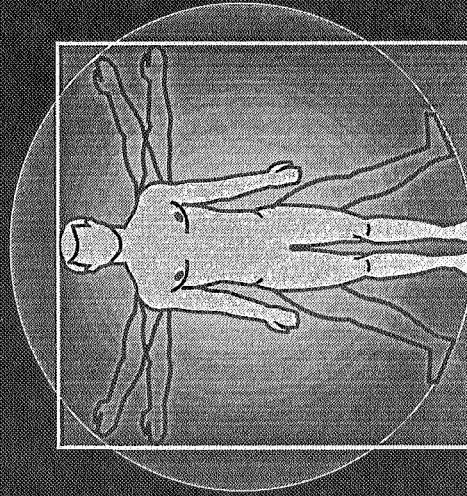


McDonnell Douglas

First Principles

"Man is the measure of all things" ... Leonardo Da Vinci

Effect of Passenger Count:



- Passenger height is discrete, not rubber.
- Passengers can stand in very large wings only.
- Passengers in the wing doesn't win until there are 2 decks.

McDonnell Douglas

First Principles

Cabin Packaging Constraints:

- 800 Passengers & Bags
- 10 square feet per passenger
- 82 inch minimum cabin height

McDonnell Douglas

First Principles

Means of Reducing Drag:

- Vortex Drag
- Friction Drag
- Separation Drag
- Compressibility Drag
- Maximize wingspan
- Minimize surface area
- Streamlined shapes
- Minimize thickness & lift

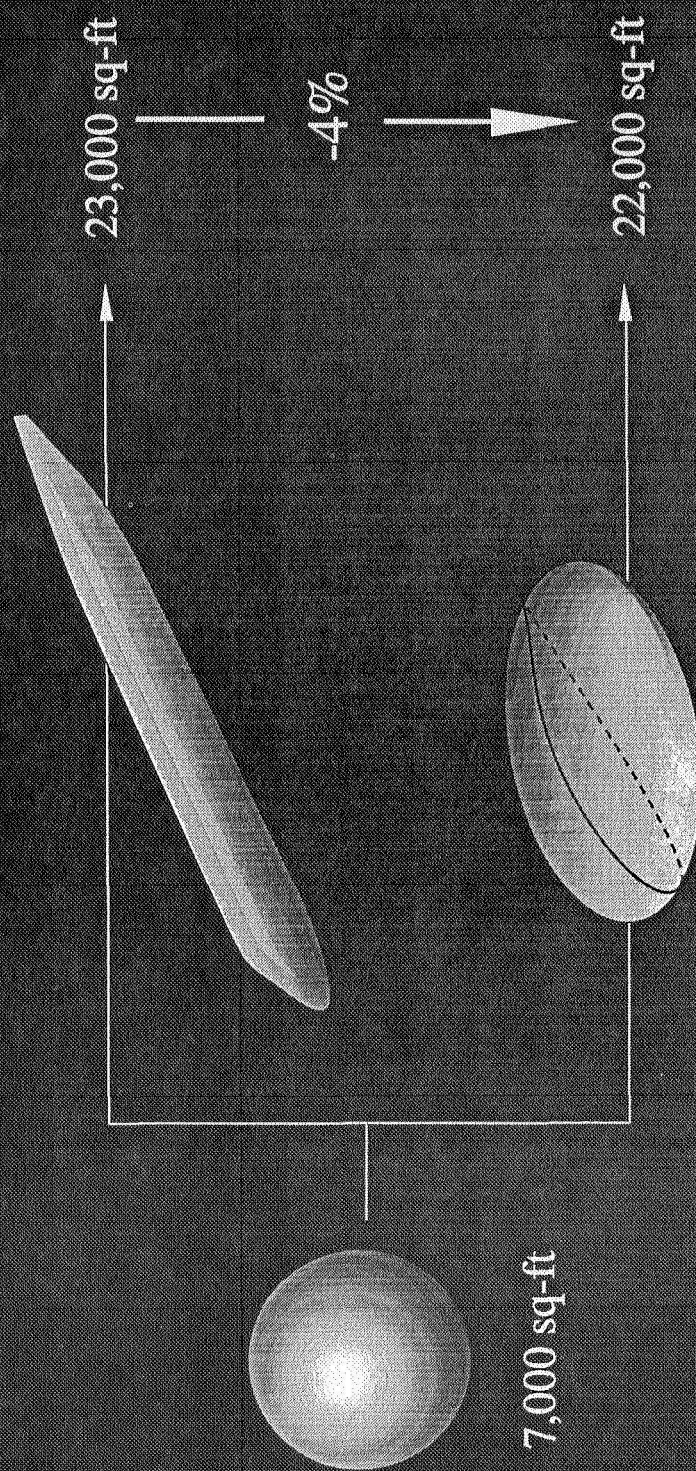
McDonnell Douglas

Effect of Body Type

Minimum Surface Area

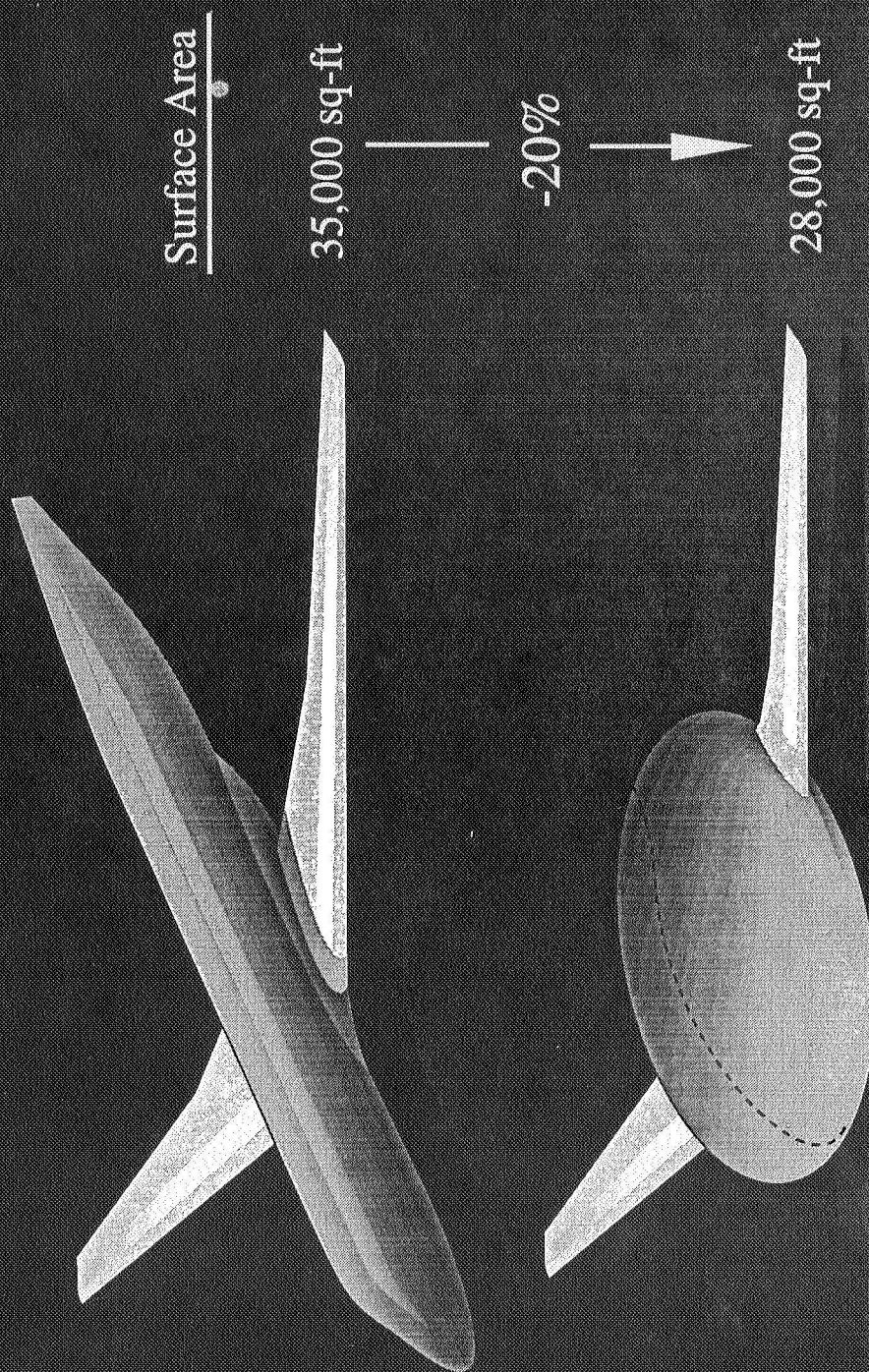
Streamlined Options

Surface Area



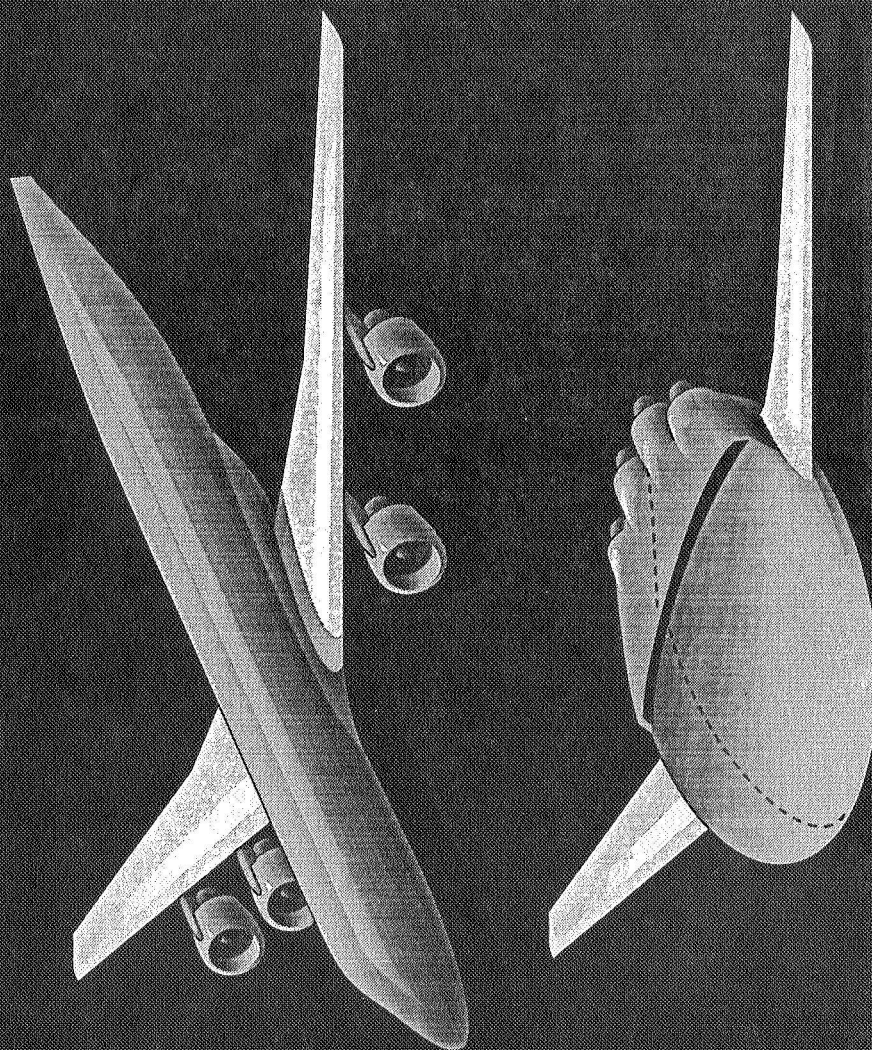
McDonnell Douglas

Effect of Wing/Body Integration



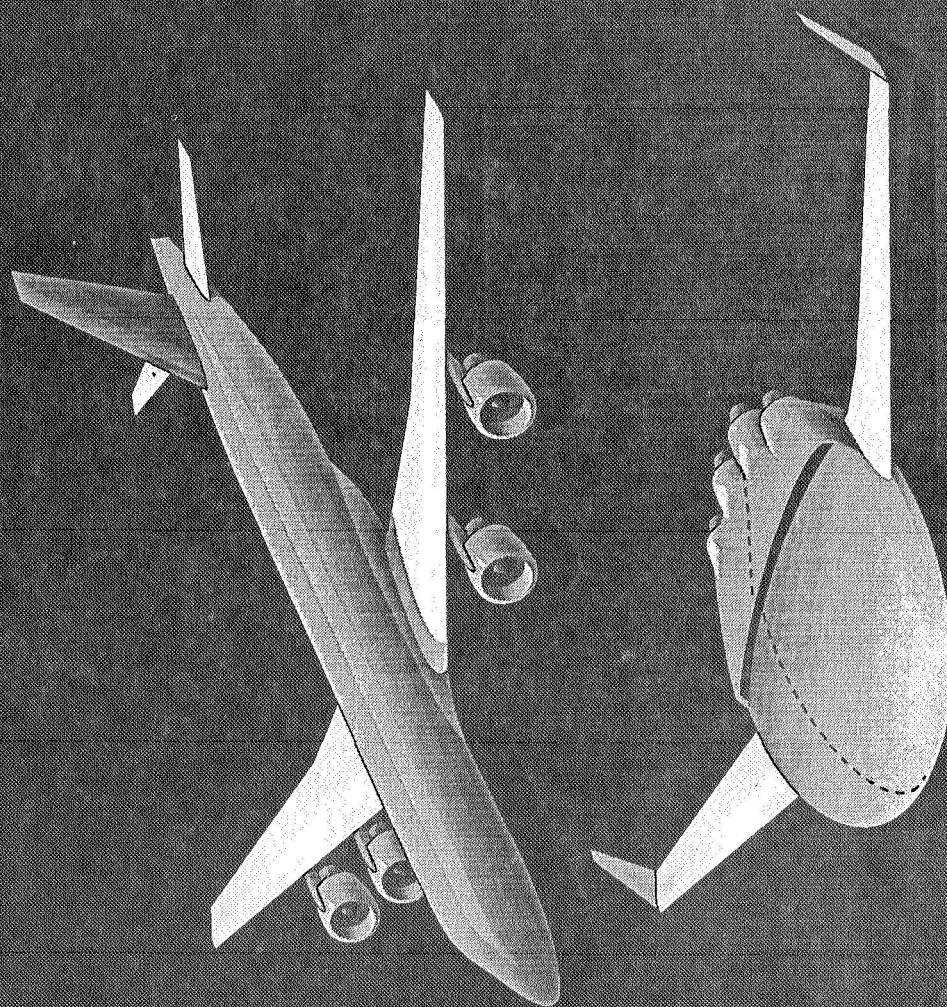
McDonnell Douglas

Effect of Engine Installation



McDonnell Douglas

Effect of Controls Integration



Surface Area

44,000 sq-ft

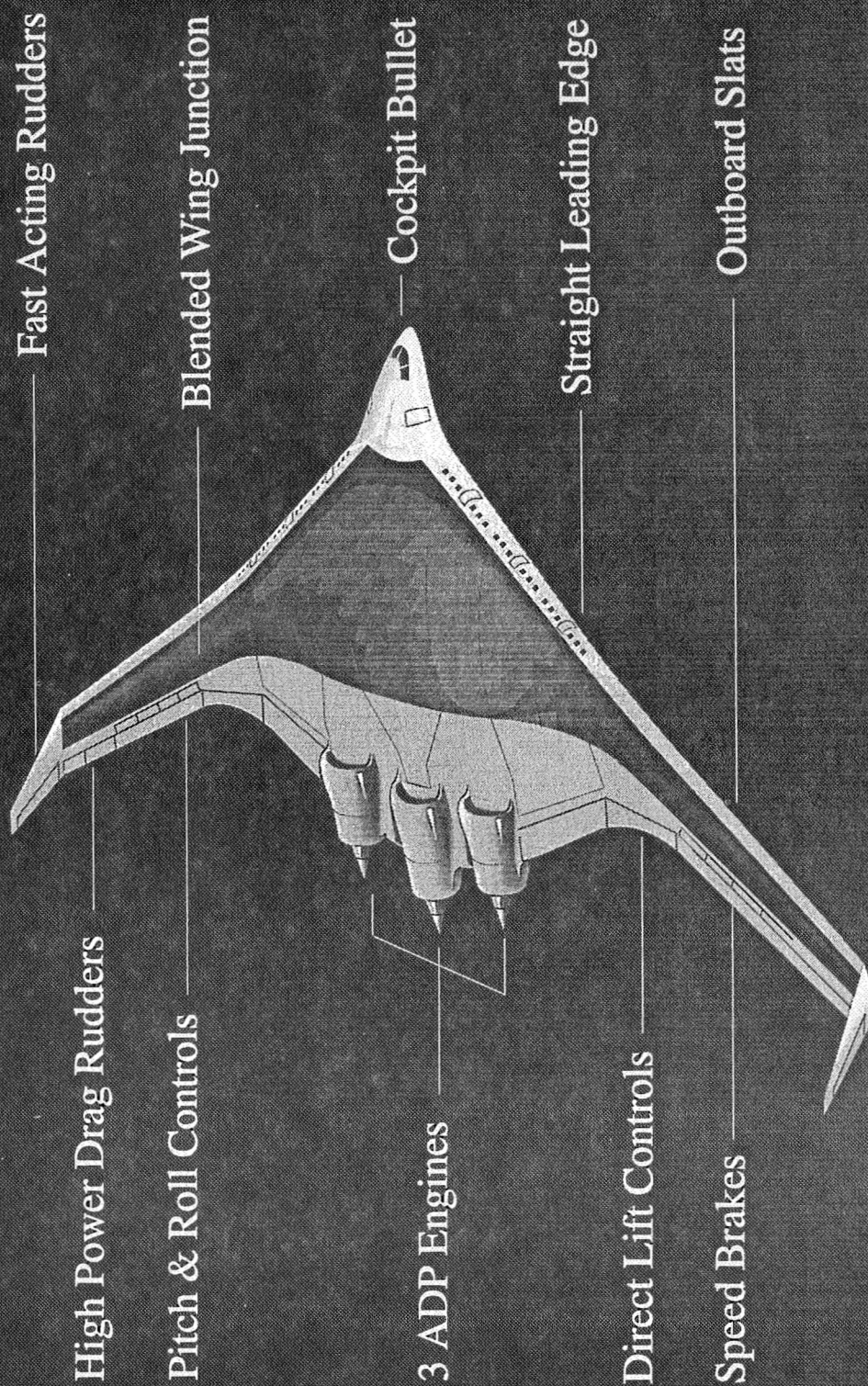
— —
-33%

29,700 sq-ft

McDonnell Douglas

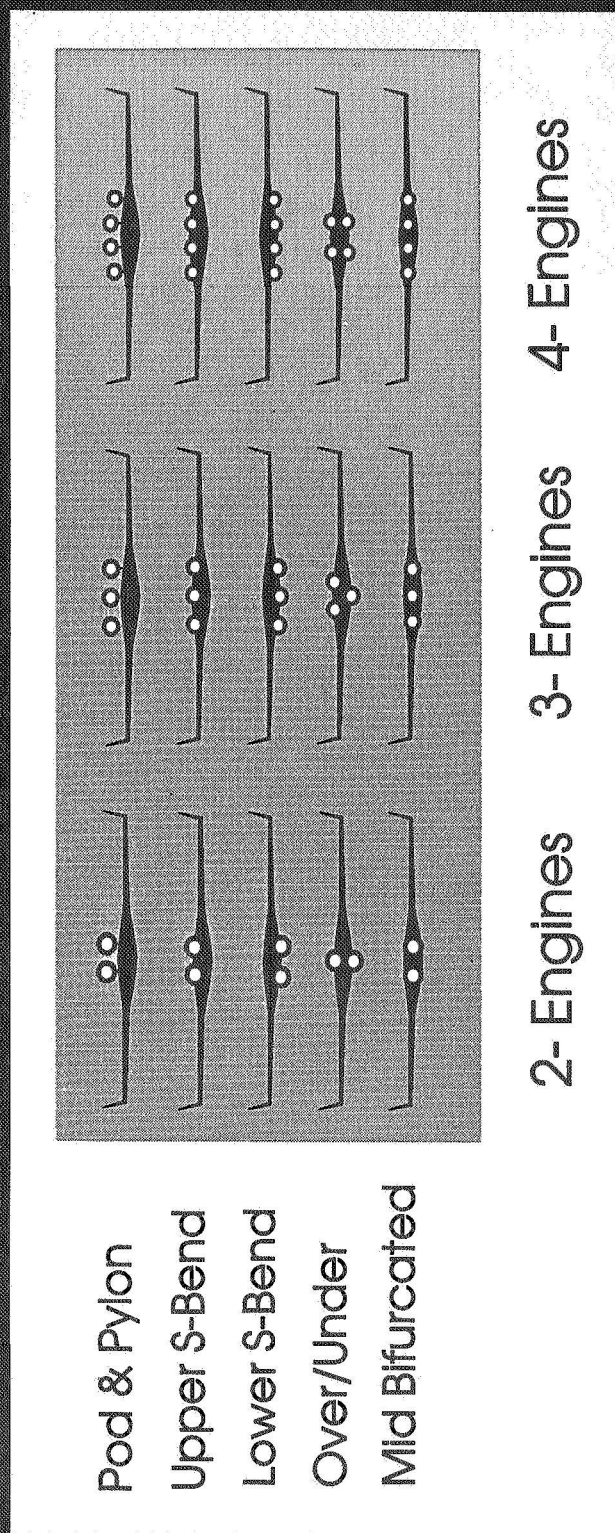


Current BWB Configuration

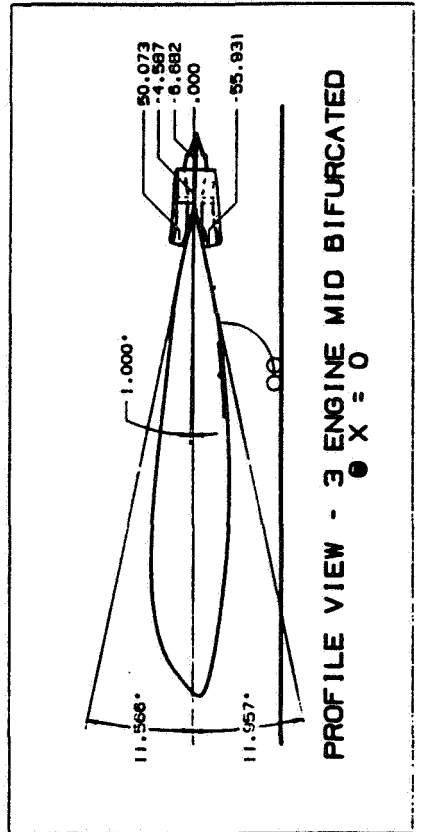
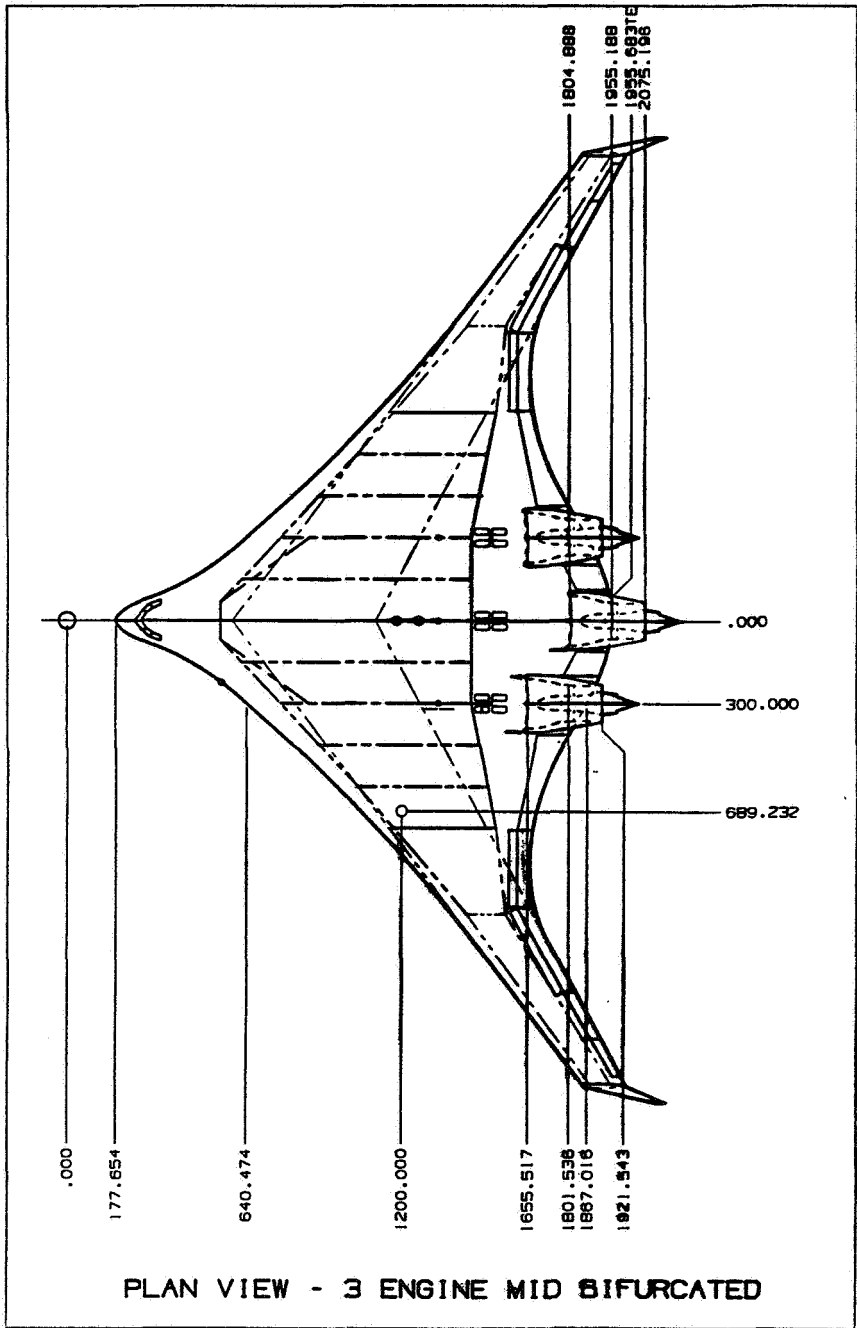


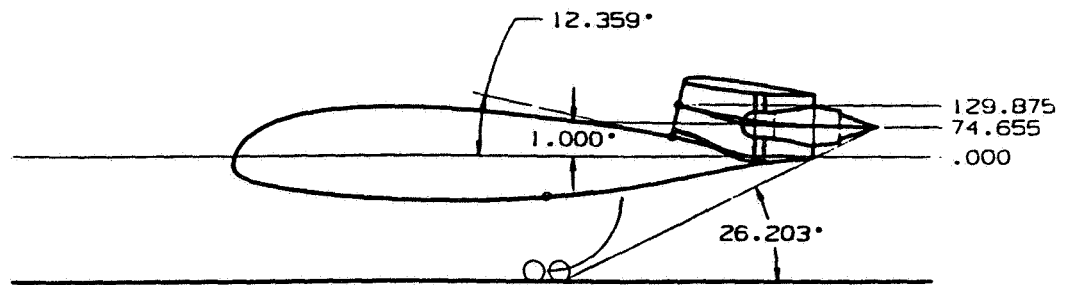
McDonnell Douglas

Alternate Engine Installation Study

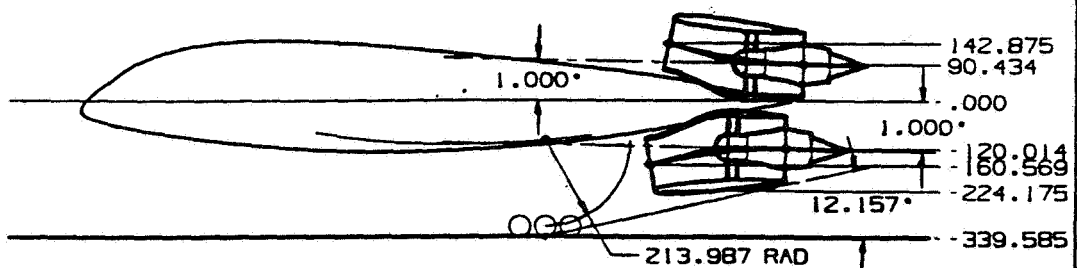


McDonnell Douglas





PROFILE VIEW - 2 ENGINE OVER
 @ X = 225



PROFILE VIEW - 2 ENGINE VERTICAL
 @ X = 0

Cabin Arrangement Study

Cabin Design Issues:

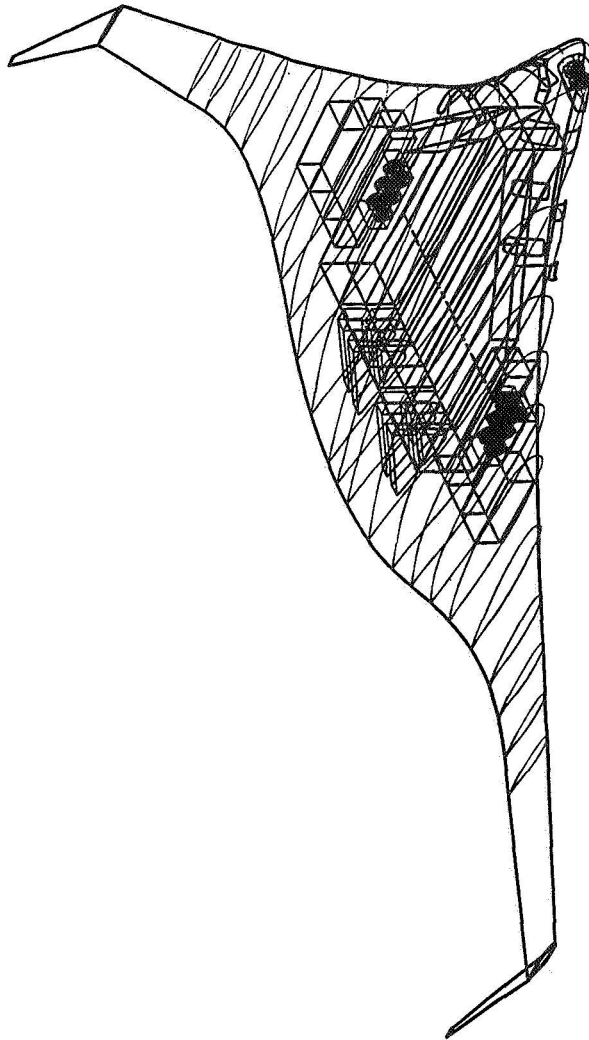
- Door & aisle height
- Airfoil wrapping
- Cabin loading & emergency egress
- Leading edge sweep
- Continuous aft pressure bulkhead
- Bending relief
- Pressure vessel surface area
- Standard LD containers for cargo
- Landing gear rigging

Design Variables:

- Upper & lower bay count
- Bay length
- Cargo bay location

McDonnell Douglas

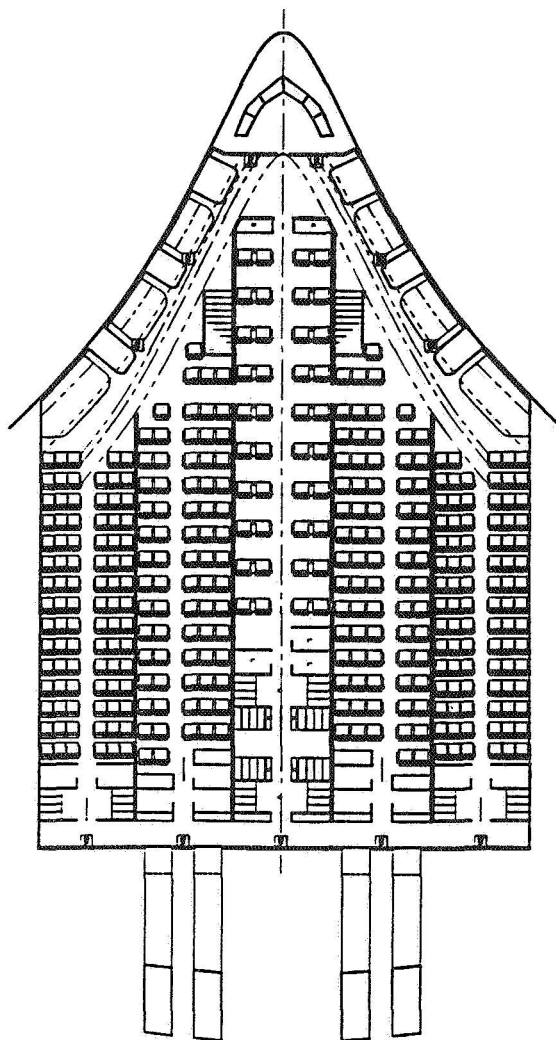
Interior Arrangement



Isometric View

McDonnell Douglas

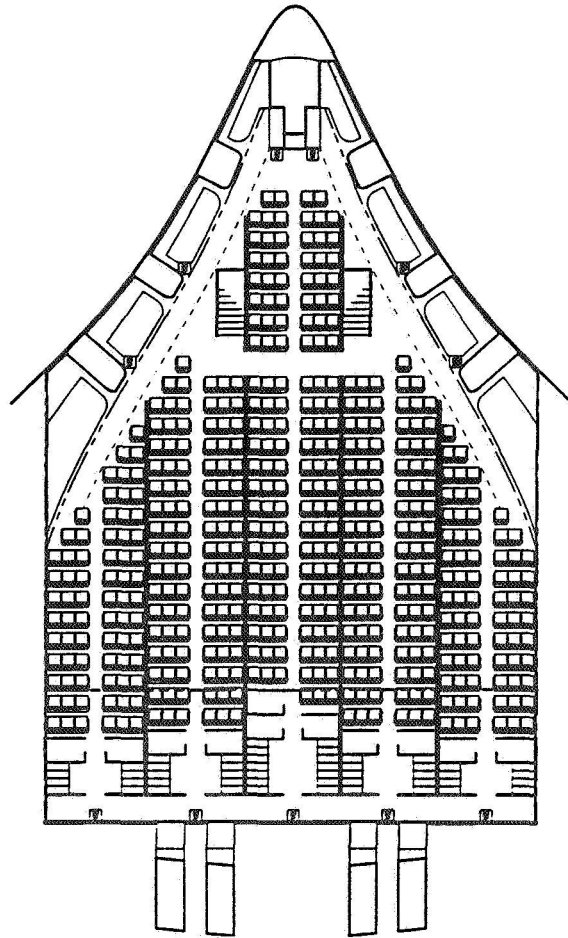
Interior Arrangement



Upper Cabin Planview

McDonnell Douglas

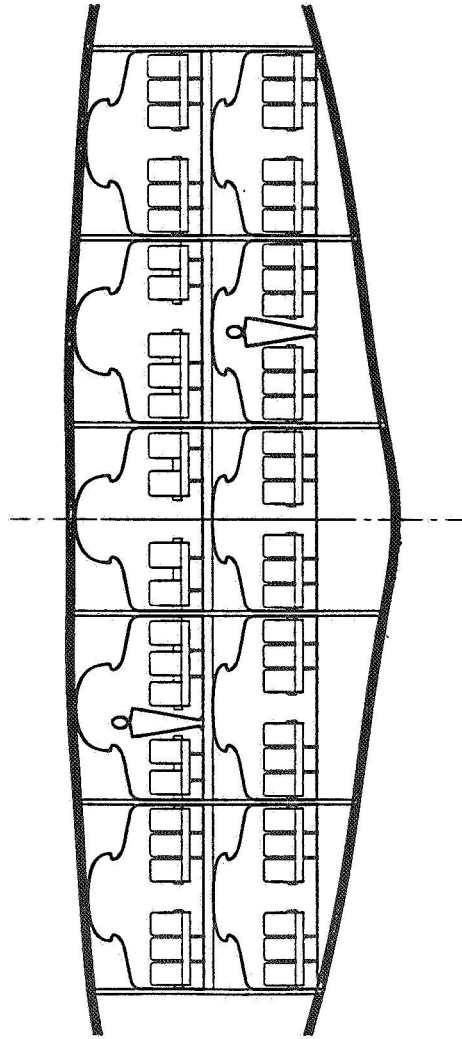
Interior Arrangement



Lower Cabin Planview

McDonnell Douglas

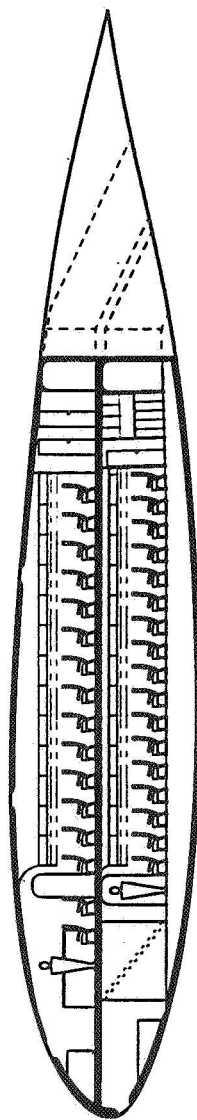
Interior Arrangement



Cabin Frontal View

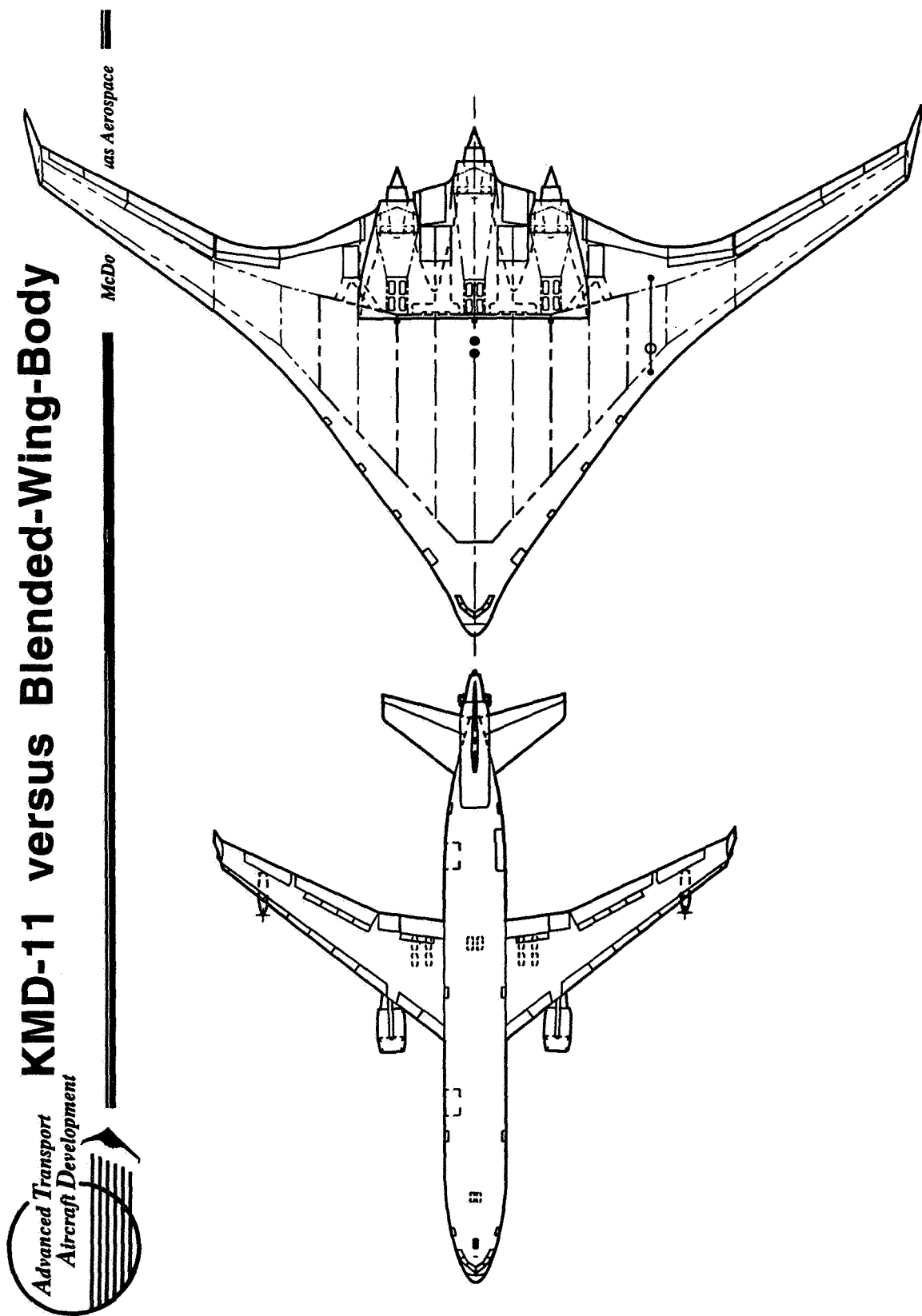
McDonnell Douglas

Interior Arrangement



Inboard Profile View

McDonnell Douglas



Sizing Results Comparison

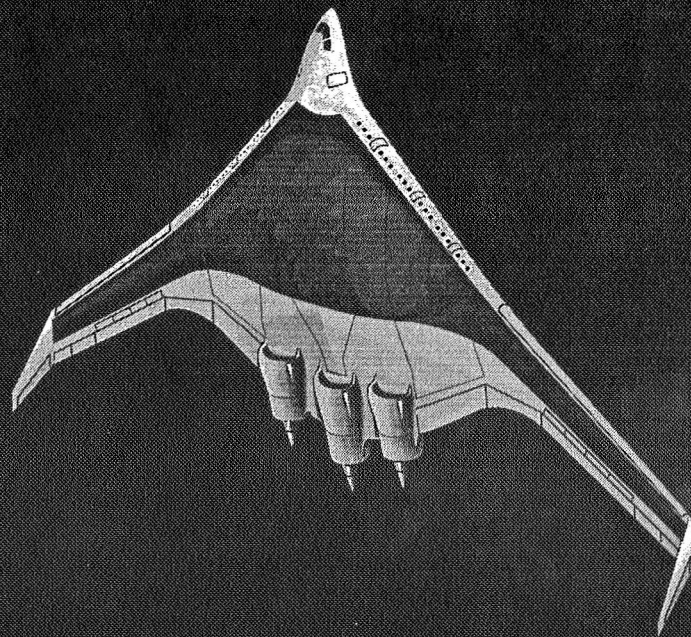
Model	Blended-Wing-Body	Conventional	B-747-400
Passengers	800	800	421
Range	NM	7000	7077
TOGW	LB	804,813	870,000
OEW	LB	413,819	400,100
Fuel Burned	LB	182,663	351,000
L/D @ Cruise		25.35	~19
Wing Span	FT	280	211
Wing Area (trap)	FT ²	7840	5500
Total Thrust, SLS	LB	202,968	227,000
Thrust-to-Weight Ratio		0.252	0.261
TSFC	(LB/hr)/LB	0.439	~0.55

McDonnell Douglas

Blended-Wing-Body BWB

Range = 7,000 nmi
 TOGW = 804,000 lbs
 Wing Area = 7,840 sq-ft
 Wingspan = 280 ft

800 Pax in mixed class seating
 Double-deck cabin
 Stitched RFI Structure
 Simple high-lift system



BWB performance relative to
 a Conventional Configuration.

TOGW	- 13%
L/D	+ 35%
Fuel-Burn	- 31%
OEW	- 9%
Thrust	- 16%
Airframe Cost	- 10%

McDonnell Douglas

516-03

39482

**Large Capacity
Oblique All-Wing Transport Aircraft**

**Thomas L. Galloway
James A. Phillips
Robert A. Kennelly, Jr.
NASA Ames Research Center
Moffett Field, CA**

**Mr. Mark H. Waters
Thermosciences Institute, ELORET Corp.
Palo Alto, CA**

**Transportation Beyond 2000:
Engineering Design for the Future**

September 26-28, 1995

INTRODUCTION

Dr. R. T. Jones first developed the theory for oblique wing aircraft in 1952, and in subsequent years numerous analytical and experimental projects conducted at NASA Ames and elsewhere have established that the Jones' oblique wing theory is correct. Until the late 1980's all proposed oblique wing configurations were wing/body aircraft with the wing mounted on a pivot. With the emerging requirement for commercial transports with very large payloads, 450 - 800 passengers, Jones proposed a supersonic oblique flying wing in 1988. For such an aircraft all payload, fuel, and systems are carried within the wing, and the wing is designed with a variable sweep to maintain a fixed subsonic normal Mach number. Engines and vertical tails are mounted on pivots supported from the primary structure of the wing. The oblique flying wing transport has come to be known as the Oblique All-Wing transport (OAW).

Initial studies of the OAW were conducted by Van der Velden first at U.C. Berkeley⁽¹⁾ in 1989 and then at Stanford in collaboration with Kroo⁽²⁾ in 1990. A final document summarizing this work is given in the thesis by Van der Velden⁽³⁾. Many issues regarding the design were identified in these studies, among them the need for the OAW to be an unstable aircraft.

Also at Stanford, Morris had successfully built and flown a powered model with a 10 foot wing span and a fixed 30 degree wing sweep during this same period. His intent was to study low speed handling of an OAW during taxi, takeoff, low speed maneuvering, and landing. To the extent that this model demonstrated that such a vehicle can fly, the project was successful. But with no instrumentation the results were strictly qualitative. In mid-1990, Morris and Kroo of Stanford along with R. T. Jones proposed to NASA Ames to build an instrumented model with an on-board computer. The wing was to have a wing span of 20 feet and have the capability to vary the wing sweep from 0 to 45 degrees. This proposal was accepted, and it stimulated additional in-house work at NASA Ames to study the total concept of the OAW as a commercial transport, and to design and build a wind tunnel model for test in the Ames 9 by 7-ft Supersonic Wind Tunnel. The decision to proceed with the OAW project led to the following in-house and industry activities over the period from early 1991 to the end of 1994.

	<u>Completed</u>
Systems Analysis Study at NASA Ames	7/91
Conceptual Design by Frank Neumann of Boeing	12/91
AIAA Papers — Structures/Aero & Economics by NASA Ames ⁽⁴⁾⁽⁵⁾	8/92
Configuration & Airport Interface Study by Boeing ⁽⁶⁾	6/93
Design study by the University of Kansas	6/93
Wind Tunnel Test Design Team established at NASA Ames	7/93
Aerodynamics & Stability-Control by McDonnell-Douglas ⁽⁷⁾	10/93
20' Model Ground & Flight Test by Stanford University ⁽⁸⁾	5/94
Supersonic Wind Tunnel Test at NASA Ames	8/94
Mission Analysis Study by McDonnell-Douglas ⁽⁹⁾	12/94

This presentation gives the highlights of the total project. The references listed at the end of this Introduction are all the documents that have resulted from the project. The remaining document to be completed and undoubtedly the most important is the report of the wind tunnel test which will not only present test results but demonstrate the agreement that was obtained between CFD studies and the test data.

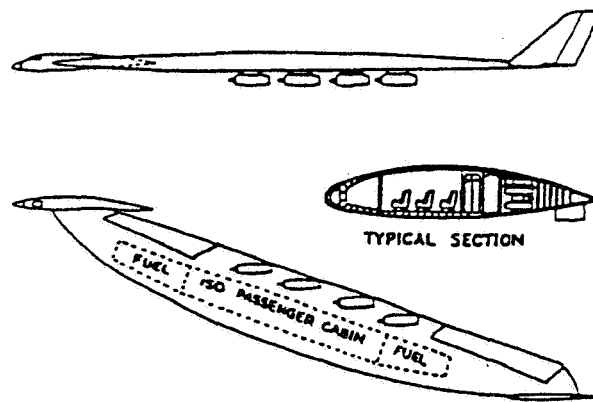
REFERENCES

1. Van der Velden, A., "The Conceptual Design of a Mach 2 Oblique Flying Wing Supersonic Transport", NASA Contractor Report 177529, May, 1989.
2. Van der Velden, A., Kroo, I., "The Aerodynamic Design of the Oblique Flying Wing Supersonic Transport", NASA Contractor Report 177552, June, 1990.
3. Van der Velden, A., "Aerodynamic Design and Synthesis of the Oblique Flying Wing Supersonic Transport", Stanford University Report SUDDAR 621, June, 1992.
4. Waters, M., Ardema, M., Roberts, C., Kroo, I., "Structural and Aerodynamic Considerations for an Oblique All-Wing Aircraft", AIAA Paper No. 92-4220, Aircraft Design Systems Meeting, August, 1992, Hilton Head, SC.
5. Galloway, T., Gelhausen, P., Moore, M., Waters, M., "Oblique Wing Supersonic Transport Concepts", AIAA Paper No. 92-4230, Aircraft Design Systems Meeting, August, 1992, Hilton Head, SC.
6. Anon., "Cooperative Program to Develop an Oblique All-Wing Supersonic Passenger Transport", Boeing Commercial Airplanes, Final Report Task 13 NAS1-19345, May, 1993.
7. Agrawal, S., Liebeck, R., Page, M., Rodriguez, D., "Oblique All-Wing Configuration Aerodynamics & Stability and Control", Douglas Aircraft Company-McDonnell Douglas Corporation, Final Report Task 18 NAS1-19345, October, 1993.
8. Morris, S., Tigner, B., "Flight Tests of an Oblique Flying Wing Small Scale Demonstrator", AIAA Paper No. 95-3327-CP, Guidance, Navigation and Control Conference, August, 1995, Baltimore, MD.
9. Rawdon, B., Scott, P., Liebeck, R., Page, M., Bird, R., Wechsler, J., "Oblique All-Wing SST Concept", McDonnell Douglas Aerospace, Final Report Task 55 NAS1-19345, MDA Report Number CRAD-9103-TR-9926, December, 1994.
10. Lee, G.H., "Slewed Wing Supersonics," The Aeroplane, Vol. 100, March 3, 1961, pp 240-241
11. Anon., Proceedings of the Ninth Annual Summer Conference, NASA/USRA University Advanced Aeronautics Design Program and Advanced Space Design Program, University of Kansas Paper, pp 48-56, Houston, TX, June, 1993.
12. Cheung, S., "Viscous CFD Analysis and Optimization of an Oblique All-Wing Transport, NASA CDCR-20005, Contract NCC-2-617, November, 1994.

Figure 1 Recent Oblique All-Wing Transport Activities

The concept of an oblique all wing aircraft was first proposed by Lee⁽¹⁰⁾ in the early 1960's, but subsequent research on oblique wing aircraft up to the mid 1980's concerned oblique wing/body aircraft with the oblique wing pivoted from a conventional fuselage. The 3-view sketch below shows the concept proposed by Lee.

With the emerging requirement in the mid-1980's for commercial transports with very large payloads, 450 - 800 passengers, Dr. R. T. Jones proposed an oblique flying wing. His work was carried on at Stanford University in 1988 - 1990 with grants from NASA Ames. In 1991, NASA Ames became directly involved. The Ames work included in-house studies in collaboration with Stanford, funded studies at both the Boeing Commercial Airplane Company and the McDonnell-Douglas Corporation, a contract with Stanford to build and fly a radio controlled 20 foot model, the design, construction, and supersonic wind tunnel test of a 7.5 foot span fully instrumented model, and finally a second contract with McDonnell-Douglas. The work at the University of Kansas was done independently as part of a grant from the NASA Advanced Design Program⁽¹¹⁾.



Oblique All Wing Concept
(Circa 1961)

Recent Oblique All-Wing Transport Activities

ACTIVITY	1986	1987	1988	1989	1990	1991	1992	1993	1994
R. T. JONES CONCEPTS									
STANFORD STUDIES									
NASA AMES SYSTEM STUDIES									
BOEING IN-HOUSE ASSESSMENT									
U. of KANSAS STUDY									
BOEING/DOUGLAS CONTRACTED STUDY									
20ft. MODEL GROUND & FLIGHT TEST									
AMES WIND TUNNEL TEST									
DOUGLAS CONCEPTS STUDY									

Figure 2 Original Stanford Configuration

The 3-view given below is the final arrangement for the OAW that evolved from the studies at Stanford completed in 1990. This work established the general arrangement for the OAW with the cabin in the center section toward the leading edge of the wing, the fuel tanks outboard of the cabin in both wings, four pivoting engines mounted on the front spar of the wing, multiple strut landing gear with approximately an equal distribution of weight between the forward and aft gear, and multiple vertical fins mounted on top of both the leading and trailing wings. This design shown in the figure below is for a cruise Mach number of 2.0, and with a design Mach number of 0.68 normal to the wing, a wing sweep of 70.1° is required. The unswept span of the wing is approximately 425 feet. The aircraft is designed to takeoff at a sweep angle of $35 - 40^\circ$. The passenger cabin has a lobed structure to take the pressure loads, and the seats are arranged so that the passengers face the leading wing tip.

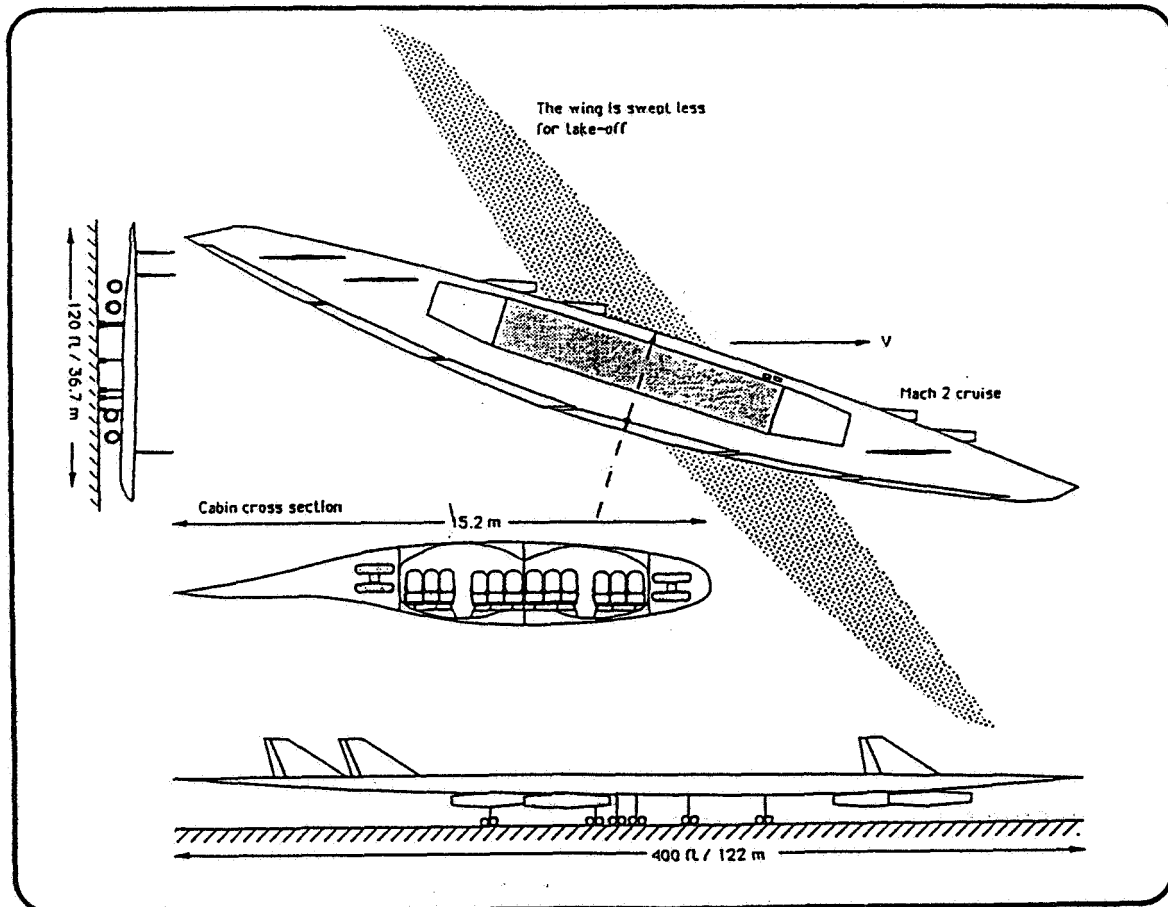


Figure 3 NASA Ames Configuration — 8/92

The in-house studies at NASA Ames which began in early 1991 resulted in the configuration shown below. This work was reported in an AIAA paper in August, 1992. The general arrangement established by Stanford was preserved, but with more attention to details such as ingress and egress, landing gear design and stowage, cockpit design, etc. The major change is that the seats are oriented to face the passengers toward the wing leading edge. This requires multiple bays for seating with a center main aisle and cross aisles into each bay. Two large galleys are shown in the aft cabin, and the cockpit is arranged in the center of the cabin and oriented for a takeoff sweep angle of 37.5° .

Main and emergency doors are designed to meet FAA requirements. There are four main doors which have to be at least 72 inches high, and there is an emergency exit at the rear of each cabin bay. These doors are 48 inches high. The leading edge has a clam-shell design for primary door access and egress, and at the rear of the cabin the emergency slide chutes are accessed through the bottom of the wing, and there are stairs, as shown, up to the top of the wing.

There are eight landing gear struts with four wheels on a single axle for each truck. The design was based on pavement loading criteria, and the intent of the single axle design is to simplify the stowage problem. Even with this design, the gear do not fit in the wing leading edge ahead of the front wing spar. This is a serious design flaw.

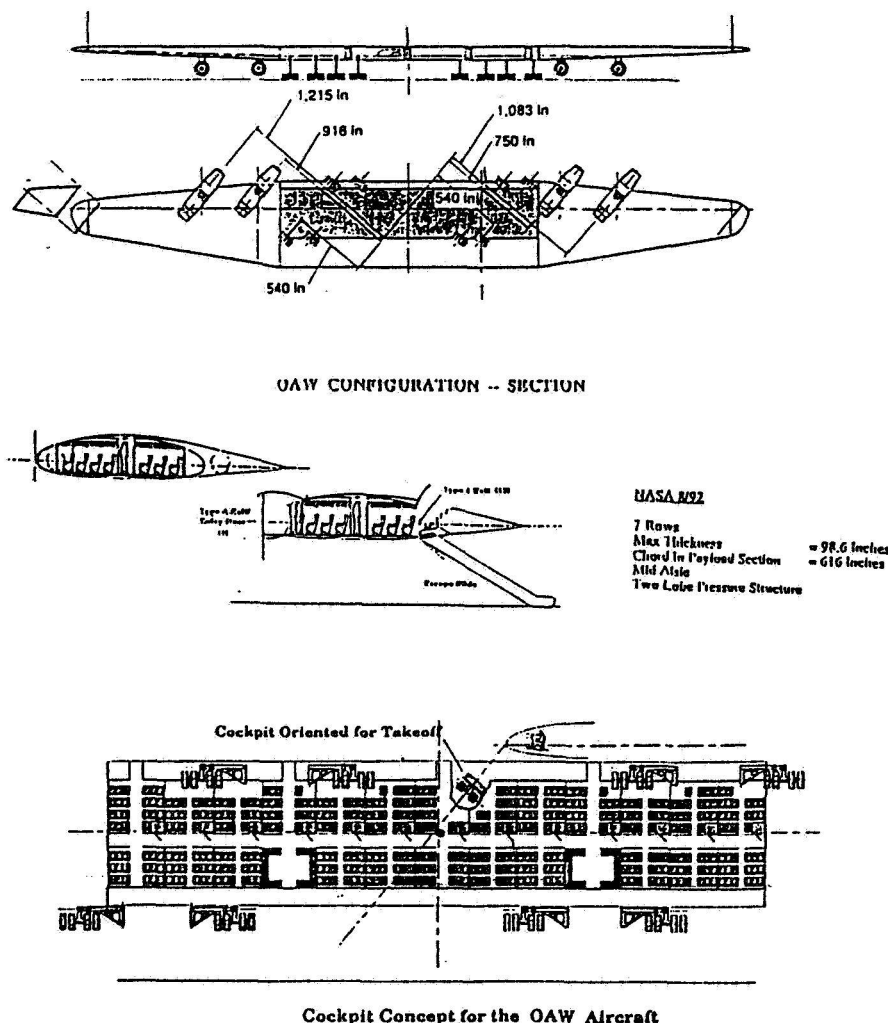


Figure 4 Boeing Configuration — 5/93
General Arrangement — OAW Configuration No. 2

The major focus of the Boeing study was to address the design from a configurator's point of view — a standard starting point for the design of a new commercial transport. The result was that the project moved from a discussion of a concept to the definition of a preliminary design which addressed most design integration, operational, and safety/regulatory issues. This was a crucial step which should have been taken earlier in the project. As a lesson learned, any innovation that must stand up to this mixture of issues should strive to establish a point design early in the project and include as much detail as possible.

A good example is the seating arrangement. There is a current FAA requirement (FAR Part 25.785) that passengers be oriented to within 18° of the direction of flight for takeoff and landing unless an energy absorbing rest or a safety harness is used to support the head. Having cabin bays angled to wing leading edge was considered, but Boeing finally decided to have the OAW aircraft takeoff straight. This meant that no yaw control was possible with the vertical fins. Instead split drag rudders provide yaw control as is done on the B-2 bomber. The drag rudders are part of the elevons in wing center section (the two panels just in-board of the wing fold).

The OAW aircraft may have too much span for a straight takeoff, Boeing shows the design with folded wing tips. The concern is violating the "obstacle free zone" (OFZ) requirements between runways and taxiways. Boeing also assumes the aircraft will taxi with zero sweep whereas previous work at NASA Ames assumes the aircraft will taxi end-on. Even with folding wing tips, there may a violation of the OFZ. Needless to say, folded wing tips is a major design consideration, and there is much difference of opinion on this subject. (continued next page)

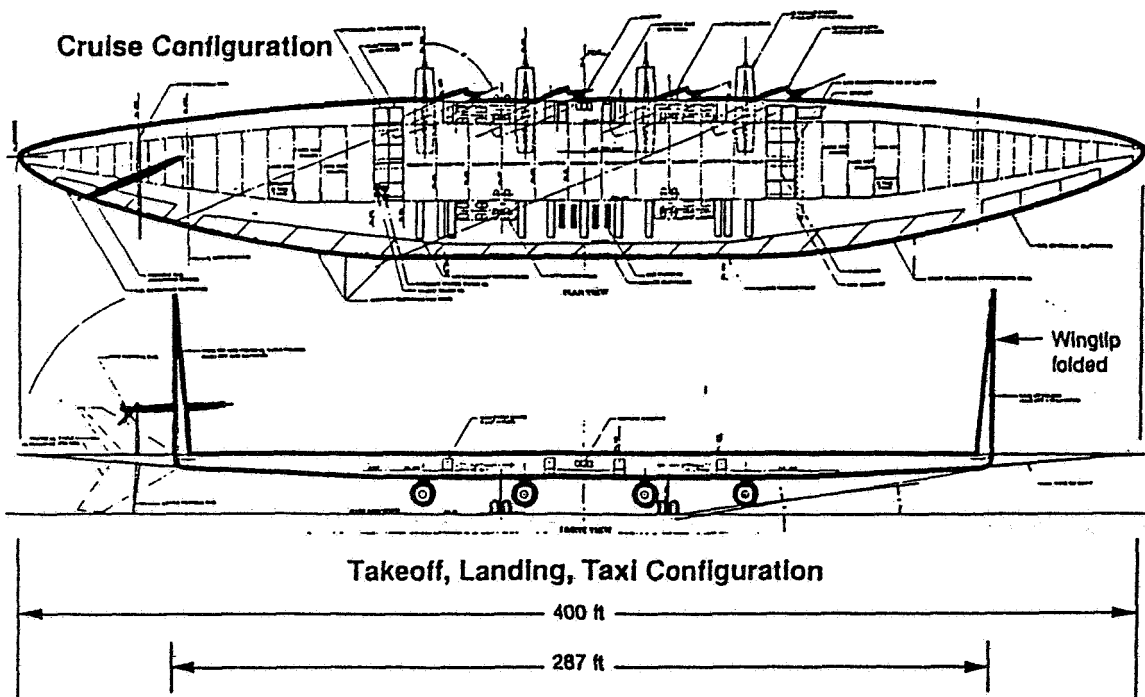


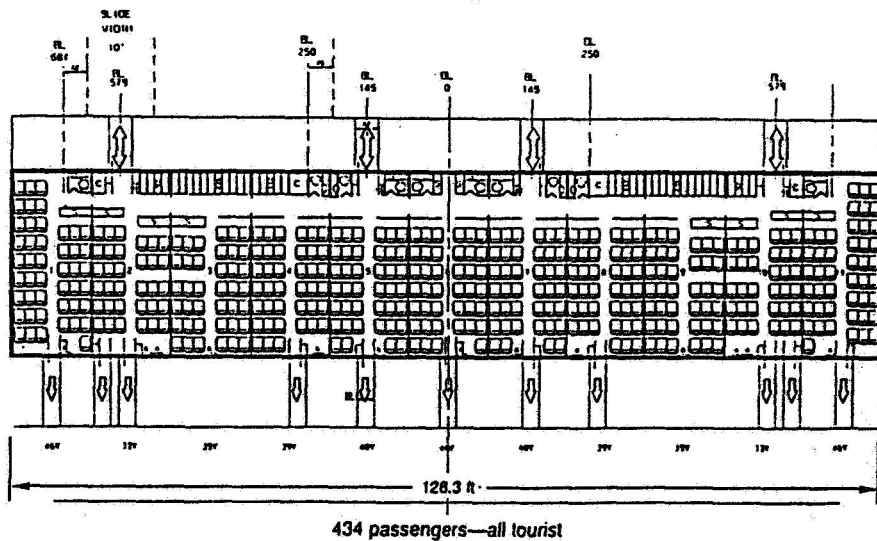
Figure 4 Boeing Configuration — 5/93
General Arrangement — OAW Configuration No. 2
(cont.)

Also, note that the engines are located in-board in the region of the cabin. The previous NASA and Stanford designs placed them outboard away from the cabin. However, Boeing felt there is more of a safety concern if engines are located near fuel tanks. In addition, it was discovered at NASA Ames that with the engines outboard the yawing moment with one engine inoperative was excessive, and it is questionable if a reasonable drag rudder system could be designed. Thus, the design shown below. The integration of the engine pivots and the landing gear into the leading edge proved to be a difficult design integration problem. To highlight this fact, the airplane designed as shown must takeoff with zero sweep because otherwise there is an interference problem between engines and landing gear.

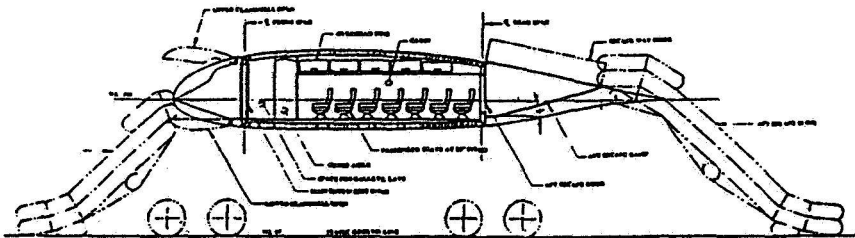
Figure 5 Boeing Configuration — 5/93

The emergency slide chutes are shown from the leading edge and from the top of the wing trailing edge. This is a departure from the NASA design which located the rear slide chutes below the wing. An above wing location is preferred for emergency ditching on water. There is a ramp at a 15° angle to get to the top of the wing at the rear, and there is some concern that this angle is too steep to meet handicapped access requirements.

Passenger Seating in 11 Cabins

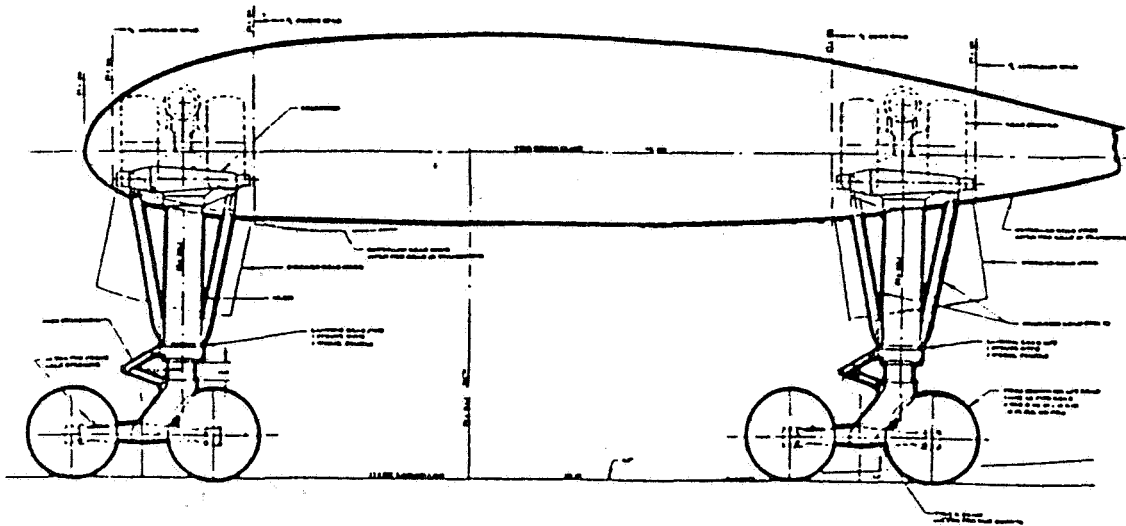


Passenger Cabin, Boarding Doors, Emergency Egress



**Figure 6 Boeing Configuration — 5/93
Landing Gear— OAW Configuration No. 2**

A great deal of attention was given by Boeing to the landing gear design. It was determined that four gear posts with four wheels each using 54" diameter tires can support airplane gross weights up to 1 million pounds without exceeding permissible pavement loading criteria. The load distribution is approximately 55% on the forward gear and 45% on the aft gear, so smaller diameter tires are possible on the aft gear. However, it is likely that all the gear would be identical for commonalty. Boeing evaluated the single axle four wheel gear proposed by NASA Ames and found it was not viable because of the requirement for a "knee joint." The gear design shown below is more conventional in that it has two axles per truck with two wheels per axle. However, there are several unique features in the design. For example, the gear are steerable up $\pm 20^\circ$ to provide the capability for ground maneuvering and cross wind landings. Also, the centerline of the truck is 22.5 inches forward of the oleo strut to allow the truck beam to be rotated into a vertical position for stowing. Being able to stow the forward gear into as small a chordwise space as possible (keeping it ahead of the forward spar) is critical to thickness requirements of the wing.



**Figure 7 Boeing Configuration — 5/93
Engine Installation— OAW Configuration No. 2**

The engine installation is shown in the lower drawing. Work on the engine cycle and inlet design was a collaboration between Boeing and NASA Ames. In the course of the work it was found that the original engine/inlet design, which used a mixed-flow turbofan engine with a design point bypass ratio of 1.5 and a normal shock inlet, was over penalizing in terms of engine size and inlet losses. As can be seen from the drawing, the engine diameter dictates the length of the landing gear. The final design shown below is a mixed flow turbofan having a design point bypass ratio of 0.6, and the inlet is an external compression conical inlet with a fixed 16° cone. The pivoting strut that supports the nacelle is cylindrical with actuators mounted from the front spar. A fairing over the full length of the nacelle encloses the pivot. In later aerodynamic work at NASA Ames, it was found that these fairings create excessive drag, and an alternative design by Boeing uses a rectangular support mounted as a piano hinge from the front spar.

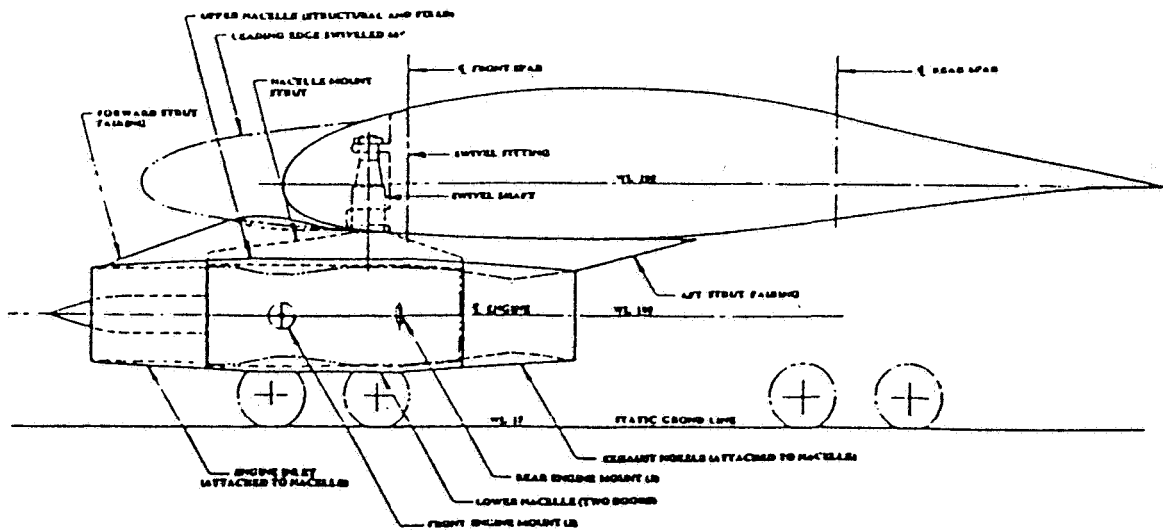


Figure 8 Economic Potential for the Oblique All-Wing Transport

To estimate the economic viability of commercial transports, NASA Ames has developed a model that addresses the return on investment (ROI) for both the airplane manufacturer and the airline. For the OAW analysis it was assumed that both achieve an ROI of 12% and that this return is achieved with a 500 unit production. Although the airplane is designed for a range of 5000 N.Mi. with full payload, a mean trip is defined to compute the economics of the airline. In this case, the range is assumed to be 3800 N.Mi. with a 65% passenger load factor. In addition, it is assumed that the aircraft is utilized for 5000 hours per year over a 15 year period.

The price of the aircraft necessary for the manufacturer to achieve a 12% ROI is determined, and using this price the passenger revenue required for the airline to achieve a 12% ROI is computed. In the chart below, the OAW is compared with an advanced subsonic transport. The values of 9 - 10 cents/revenue passenger mile for the advanced subsonic transport is consistent with average yields reported by the airline industry. For the OAW, the advantage for increased size is obvious. At a design payload of 300 passengers, the required yield for the OAW is approximately 30% greater than the advanced subsonic. At the design point of 434 passengers, the increment is a 14% increase, and at the largest design payloads considered in this study (550 passengers) the increment is approximately 9%. These values are computed assuming manufacturing complexity factors of 2.0 for the wing, vertical tail, and nacelles. The use of these complexity factors represent a large unknown for the use of advanced materials for any airplane design in the future. If the complexity factors are reduced to 1.0, the required revenue increment drops from 14% to approximately 10% at the 434 passenger design point (open square symbol on the figure below).

A large issue not included in this study is the demand elasticity — would there be a shift in appeal to the supersonic aircraft such that the average load factors for the supersonic airplane would exceed that for the subsonic airplane so that the required yield would be nominally the same. The assessment of the results given below gave rise to much optimism for the potential of a large passenger capacity supersonic OAW airplane at the time of this study in August, 1992.

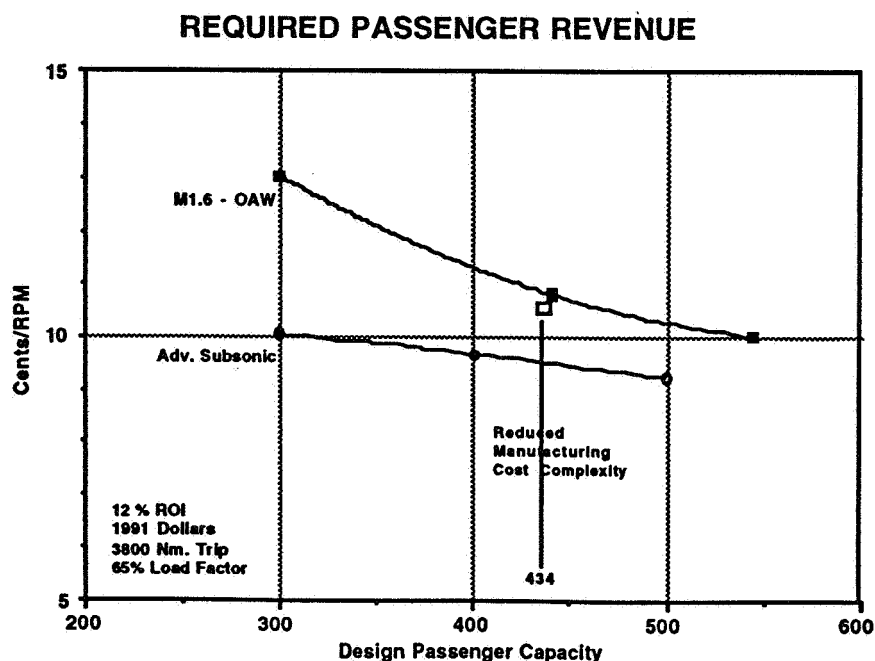


Figure 9 OAW Airfoil Geometric Requirements

An airfoil shape and section dimensions had been defined in the NASA Ames studies, but it became clear in the Boeing study that these dimensions were unrealistically low. The airfoil given in the sketch below is not a shape defined by aerodynamic analyses. Instead, it is a sketch that serves to define geometric control points defined by Boeing. These control points were used by NASA Ames and McDonnell Douglas in all of their subsequent aerodynamic CFD studies and in the design of the wind tunnel model. The definitions for the control points are summarized as follows:

Space to stow the forward landing gear

- Distance from the leading edge to the forward spar 80"
- Wing thickness (outside dimension) at the front of the forward spar 92"

Location of the front edge of the pressurized cabin (inside of the cabin)

- Distance from the leading edge to the front edge of the cabin 95"
- Wing thickness (outside dimension) at the front edge of the cabin 96"

Location of the rear edge of the pressurized cabin (outside of the cabin)

- Distance from the leading edge to the aft edge of the cabin 420"
- Wing thickness (outside dimension) at the aft edge of the cabin 87"

Location of the rear edge of the aft landing gear bay (outside the bay)

- Distance from the leading edge to the aft edge of the bay 499"
- Wing thickness (outside dimension) at the aft edge of the bay 59"

AIRFOIL WITH DESIRABLE FEATURES

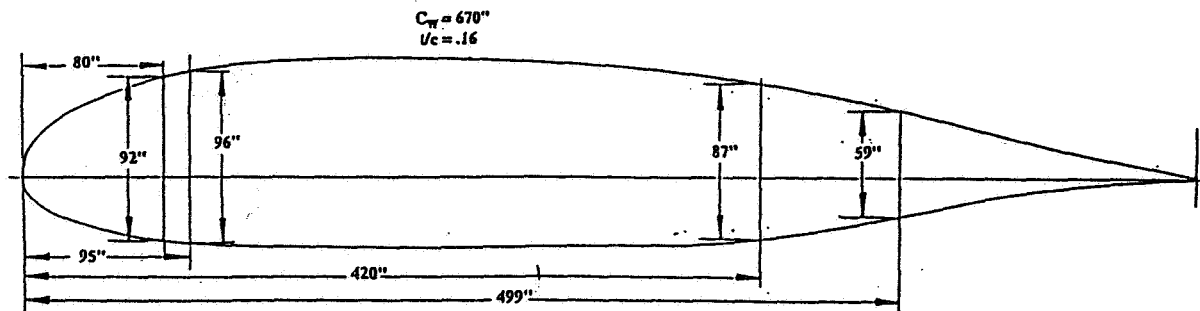


Figure 10 OAW Airfoil CFD Studies

The figures below hardly do justice to the large body of work conducted at both NASA Ames and McDonnell-Douglas on CFD analyses of the wing. The report prepared by Cheung¹² is an excellent summary of the analytical studies conducted at NASA Ames which led up to the final design for the wind tunnel model.

In the work at NASA Ames and McDonnell-Douglas it was found that viscous effects were very important, and Euler codes were not sufficient for an acceptable design. McDonnell-Douglas compared results on a baseline wing using four different Navier-Stokes codes all using a common grid and the same turbulence model, and the closeness of the results were "surprisingly excellent" as stated by the MDA author. Shown below are particle traces in the boundary layer flow for an interim NASA Ames design but computed at McDonnell-Douglas. The figure on the left represents the planned wind tunnel Reynolds number of 5.7 million, and the one on the right is representative of the Reynolds number in flight — 200 million. The Reynolds number (Re_c) is based on the wing centerline chord normal to the wing leading edge. It is apparent that the flow is highly three dimensional at the low Re_c , and a shock wave has formed near the trailing wing tip. In contrast, no separation is apparent at the flight Re_c .

McDonnell Douglas also conducted CFD analyses using inverse methods where the airfoil section shape is perturbed locally to achieve a desired pressure distribution. These results are promising in that they were able to improve aerodynamic smoothness.

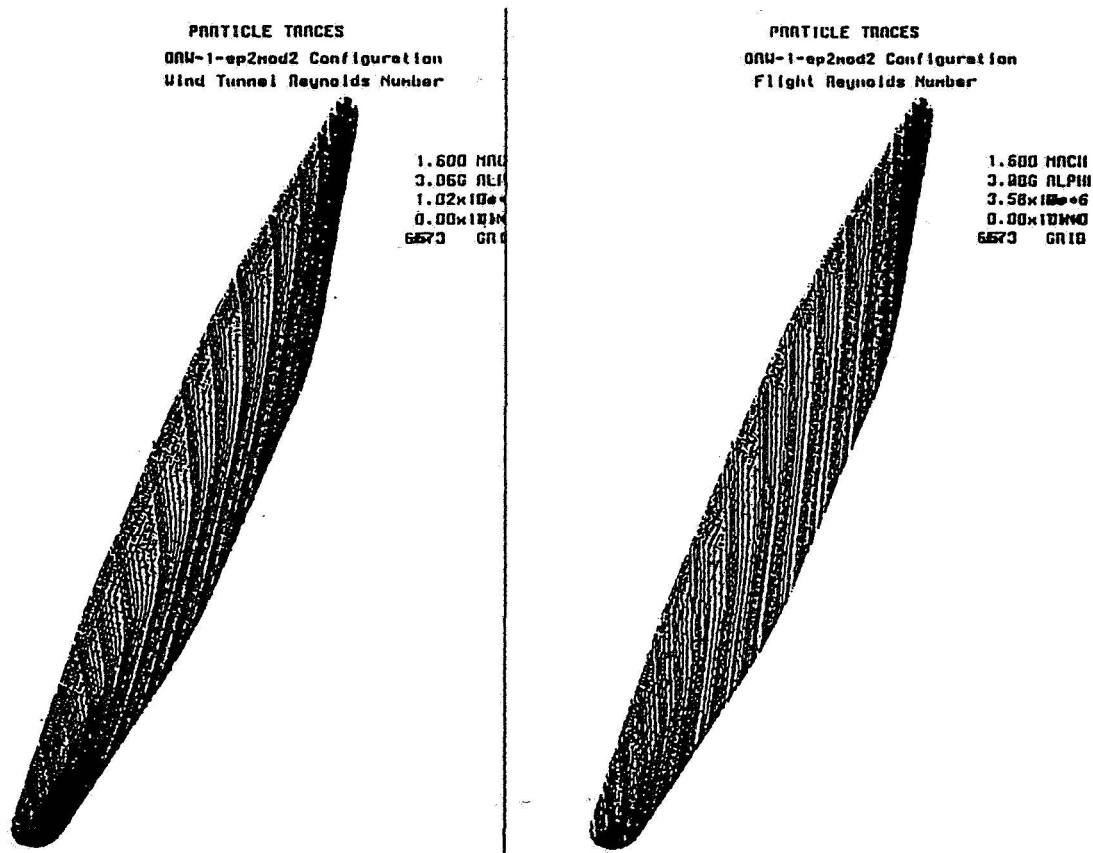


Figure 11 OAW Idealized Cruise Lift-Drag

At the outset of the OAW work at Stanford and in the initial studies at NASA Ames, there was much optimism in the aerodynamic cruise performance of the OAW transport. The figure below is taken from a contractor study done by Stanford for the NASA, and as can be seen the OAW was predicted to have excellent lift-drag ratio (L/D) over the complete flight regime. At a flight Mach number of 2, the value of the L/D for the OAW is comparable to that for a double-delta supersonic transport. From this figure, the estimate for the L/D at a flight Mach number of 1.6 is approximately 13. The Mach number normal to the wing leading edge was chosen to be 0.68, and thus the required wing sweep is about 65° at this condition.

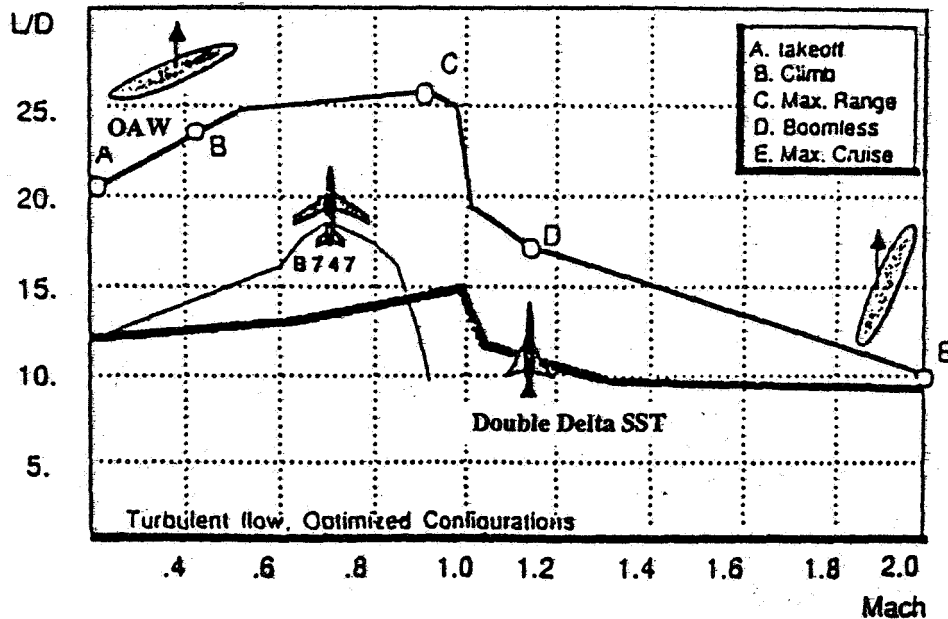
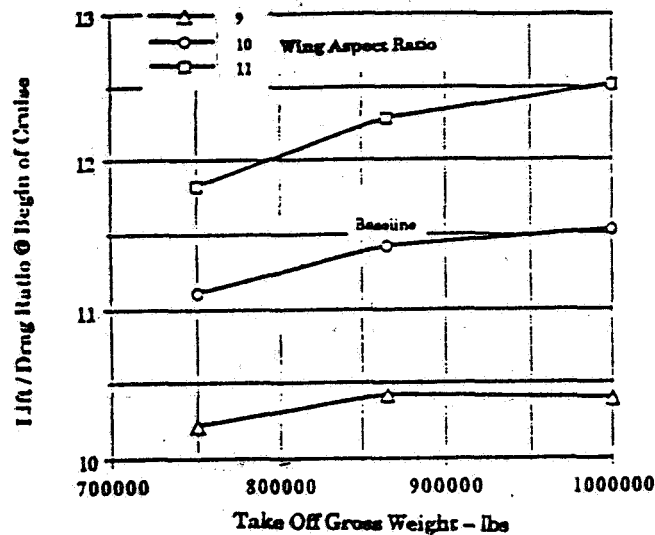


Figure 12 OAW Cruise Lift-Drag Evolution @ NASA Ames

The NASA Ames parametric results from the AIAA paper presented in August, 1992 are given in the figure below. The effect of airplane size (Reynolds number effects) and wing aspect ratio on L/D are shown, and the baseline design has an L/D of 11.46. The buildup of drag in the first column of the table is for this baseline. There are several factors that can help explain the reduction in L/D from that of the Stanford studies. These include an increase in the thickness ratio of the wing section, and more careful bookkeeping of the vertical tail and nacelle drag.

The second two columns in the table give the estimated drag buildup by NASA Ames at the conclusion of the Boeing study in May, 1993. At this time much more information was known about the size of the wing, and CFD work at Ames had identified nacelle and pylon profile drag as significant drag factors. Also, estimates of trim drag on the vertical fins had been computed. The net result is a L/D slightly greater than 10 at the Mach 1.6 cruise point. Estimates based on the wind tunnel tests have yet to be determined.



OAW Transport Aircraft Aerodynamic Drag Buildup

	NASA 8/92	NASA 5/93 (11x gross wgt)	NASA 5/93 (11x CL)
Wing Area	16542 ft ²	17261 ft ²	17261 ft ²
Cruise Altitude	1.6	1.6	1.6
Cruise Altitude	52000 ft	52000 ft	52000 ft
Dynamic Pressure	396.7 psf	396.7 psf	396.6 psf
Weight @ begin Cruise	821750 lb	821750 lb	865000 lb
Lift Coefficient	.12522	.1200	.12522
Wing Drag	.00990	.01054	.01086
Parasite	.00351	.003990	.003990
Volume Wave	.00215	.002420	.002420
Induced	.00361	.003500	.003671
Wave due to Lift	.00061	.000610	.000749
Compressibility	.00002	.000020	.000020
Vertical Tail Drag	.00021	.00045	.00045
Parasite	.000175	.000138	.000138
Wave	.000035	.000028	.000028
Trim	.0	.000284	.000284
Nacelle Drag	.00080	.00094	.00096
Nacelle Parasite	.00056	.000328	.000337
Nacelle Cowli Wave	.00007	.000164	.000169
Nacelle Boattail Wave	.00010	.000189	.000194
Nacelle Lip Bluntness	.0	.000015	.000015
Nacelle Base	.00001	.000044	.000044
Pylon Parasite	.00005	.000080	.000082
Pylon Wave	.00001	.000020	.000021
Nacelle-Wing Interference	.0	.000100	.000100
Surface Caps (Wing & Tail)	.00002	.000030	.00003
Total Drag @ Begin Cruise	.01093	.01194	.01230
Lift / Drag @ Begin Cruise	11.46	10.05	10.18

Figure 13 Idealized Bending Loads for a Span-Loaded Aircraft

The sketch below defines simply the potential advantage for any span loaded airplane in flight. With a conventional airplane, much of the gross weight is concentrated in the fuselage and combined with the lift on the wing large bending moments result at the wing root. In an idealized spanloader, weight is distributed over the wing span thus reducing the maximum bending moment considerably.

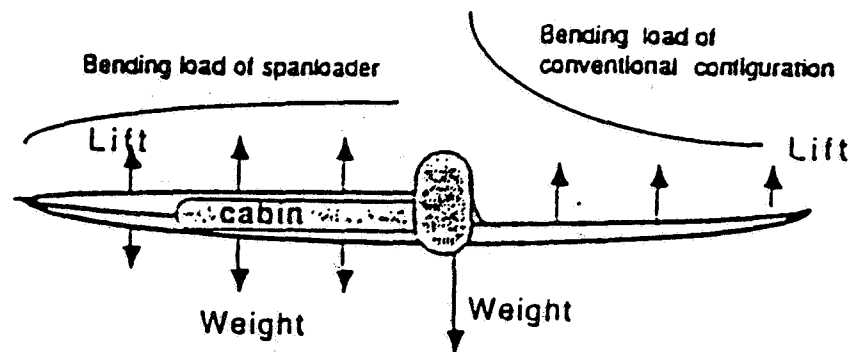
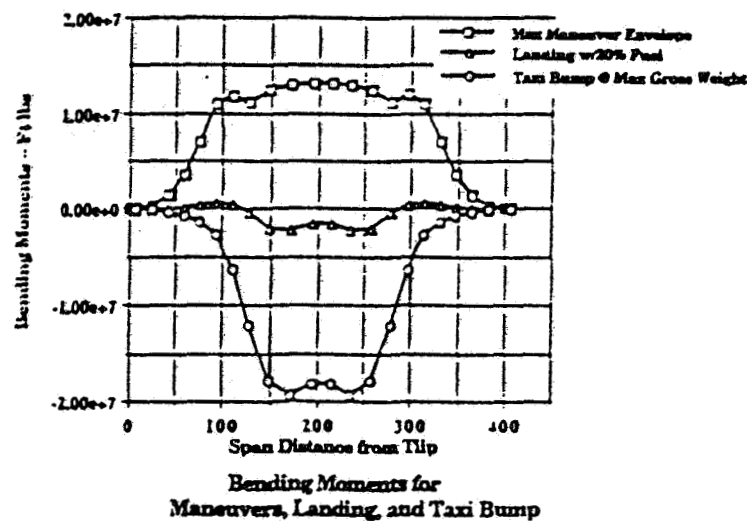
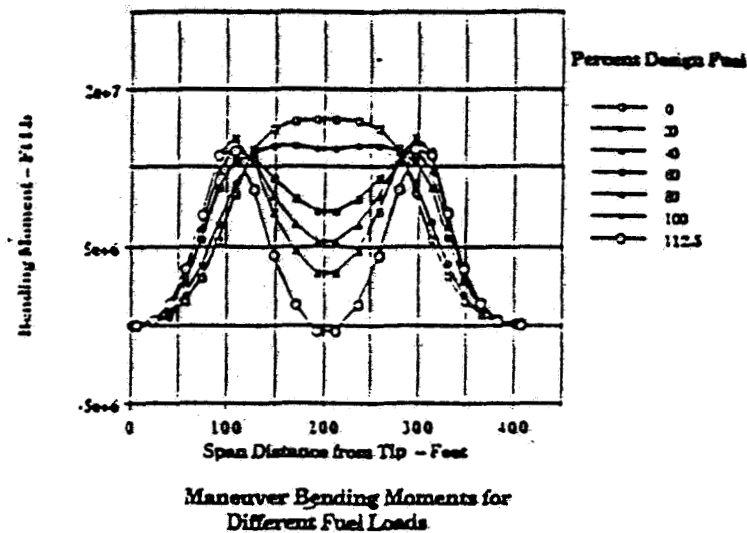


Figure 14 OAW Bending Loads & Wing Unit Weight

In the NASA Ames design of August, 1992, the outer edge of the fuel tanks were approximately 100 feet from the wing tip, and as can be seen from the set of curves on the left, there is an interesting family of bending moment curves with the aircraft in flight depending on the amount of fuel on board. The envelope for these data are given in the upper portion of the curves on the right, and indeed the bending moment distribution is nominally that of a span loader.

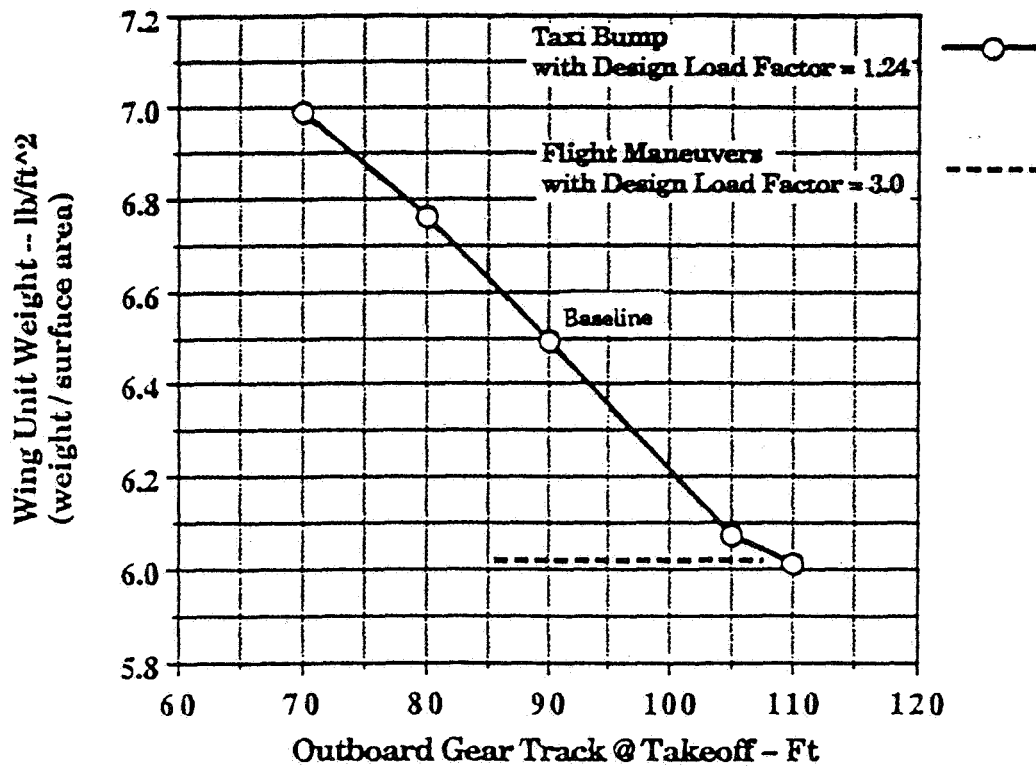
On the ground a different situation arises. Conventional transport aircraft with conventional landing gear are designed for a taxi bump with a design load factor of 2.0 (i.e., the weight acts with two times the acceleration of gravity). A study at NASA Ames concluded that the use of a double acting oleo (like that used on the C5 military transport) operating on standard commercial runways could reduce the required taxi bump design load factor to 1.24. Using that factor and a gear track of 90 feet, the bending moment distribution shown in the lower portion of the curve on the left was computed. As shown, the bending moment distribution for the taxi bump is more severe than for the flight loads. This is reflected in the estimate for wing unit weight (structural weight / wing surface area) which is shown on the following page. (continued next page)



OAW Aircraft Bending Moments

**Figure 14 OAW Bending Loads & Wing Unit Weight
(cont.)**

The bending loads due to a taxi bump are unquestionably a major concern for the OAW transport. The load factor may have to increase above the estimate of 1.24. Increasing the track of the landing is an obvious solution to the problem, but there are limits due to width of existing runways which vary from 150 to 200 feet at major airports. Airlines desire 50 feet from the landing gear to the edge of the runway which would allow a track of 100 feet for a runway width of 200 feet. The Boeing design did not consider this problem, and the gear track in their design is 58.3 feet. This can be increased to approximately 80 feet if the gear are designed to swing toward the centerline when stowed rather than away from the aircraft centerline as was done by Boeing. However, it is not clear if other design factors would preclude such a change.



**OAW Aircraft Wing Unit Weight
with Landing Gear Track**

Figure 15 OAW Stability and Control Issues

The concern for stability and control issues was the original impetus for Stanford to propose the OAW project to NASA Ames, and this subject was a major part of the first contract with McDonnell Douglas. This is a difficult subject to resolve with just an analysis, but it is safe to say enough has been learned to pose intelligent questions and propose a plan for continued work in this area. The following text is a summary of the assessment given by McDonnell Douglas in their final report.

OAW Airplane Controls

Pitch Control	Midspan and inboard elevons (pitch about the long axis)
Roll Control	Outboard Elevons
Yaw Control	Vertical Fins for High Speed
	Split Drag Rudders for Low Speed (takeoff with zero sweep)
	(Drag rudders are outboard flaps on both wings which operate functionally as a rudder)

General Positive Statements

- A stable and controllable OAW is feasible. However, aeroelastics have not been addressed, and this could present high speed problems.
- Wingtip folding appears quite controllable
- The low wing loading and attendant lack of high lift devices means that the controls are not forced to cope with severely non-linear aerodynamics.
- The static instability (-7% MAC) produces a high trimmed lift-curve slope which keeps the approach angle of attack the same as that for conventional transports and provides a CLmax way beyond that required to meet the approach speed targets. Thus, stall problems are minimized.

(continued next page)

**Figure 15 OAW Stability and Control Issues
(cont.)**

Areas of Concern or Unknown

- Aeroelastic effects may have a significant impact on cruise trim and maneuvering, especially in roll. Further, flexibility in general may produce structural mode coupling or ride quality problems
- Gust Sensitivity & Center of Rotation effects: The low wing loading and short pitch coupling of the OAW may yield poor flying and ride qualities in turbulence. In addition, cockpit placement at the wing leading edge will result in a relatively short distance from the pilot to the center of rotation which is not desirable.
- Fin Placement: Current design places the upper fin on the trailing wing in a region of extreme streamline curvature which is undesirable because the fin must rotate. In addition, the boundary layer is very thick at this location and flow separation may occur. Alternative fin locations including multiple fins on the upper surface need to be explored. For close coupled multiple fins, interference is a potential problem..
- Drag Rudder Performance: These devices often suffer from linearity and reversal problems. Wind tunnel tests are required.
- Alternate C.G. location: The current design (32% MAC) does not heavily tax the pitch controls. The effect of further aft C.G. on the airfoil design and cabin packaging may prove to be beneficial to L/D.
- Post Stall Tumbling: The OAW appears to have a solid margin between the required minimum stall speed and aerodynamic stall. However, if technology advances allow an increase in the wing loading, this will become a major issue.

Figure 16 OAW Transport Potential for Sideline Noise @ Takeoff

In the original NASA studies, the engine cycle was a mixed flow turbofan with a design point bypass ratio at sea level of 1.5. The engine was sized for cruise at Mach = 1.6, and because of the engine lapse rate, the engines were greatly oversized for takeoff. As a result the required takeoff distance could easily be achieved with the engines at part power, and the takeoff noise was very low. The estimate was made that potential Stage IV goals could be made with any of the possible airplane configurations — straight wing unfolded, straight wing folded, or swept wing (40° sweep). In all cases, the engines could have conventional convergent-divergent nozzles without noise suppressers of any kind.

As the study evolved, it became obvious that a large nacelle diameter had a strong negative effect on the design both in terms of drag and the required length of the landing gear. The engine cycle for the final design is a mixed flow turbofan with a design point bypass ratio at sea level of 0.6. As can be seen in the table below, the best that can be achieved with this engine cycle is current Stage III noise levels, and not even that if the wing is swept 35° to 40° at takeoff. If the bypass ratio is 0.8, the noise performance is improved, but again only Stage III levels are achieved. All of these estimates are with engines having conventional convergent-divergent nozzles without noise suppressers, so even with the bypass ratio 0.6 engines the noise performance is considered to be very good.

OAW Transport Aircraft Potential for Sideline Noise @ Takeoff

Engine	Straight Wing Unfolded	Straight Wing Folded	Swept Wing (40 degrees)
SLS Bypass Ratio = 0.6	Stage III	Stage III w/PLR	No Can Do
SLS Bypass Ratio = 0.8	Stage III	Stage III w/PLR maybe w/o PLR	No Can Do
SLS Bypass Ratio = 1.5	Stage IV	Stage IV	maybe Stage IV w/PLR
Stage III	Sideline Noise @ Takeoff -- 102.5 EPNdB. Measuring point 21323 feet from brake release		
Stage IV	Sideline Noise @ Takeoff -- Stage III - 4 or 5 EPNdB		
PLR	Programmed Lapse Rate Throttle reduction during gear retraction -- begin @ 35 ft altitude		

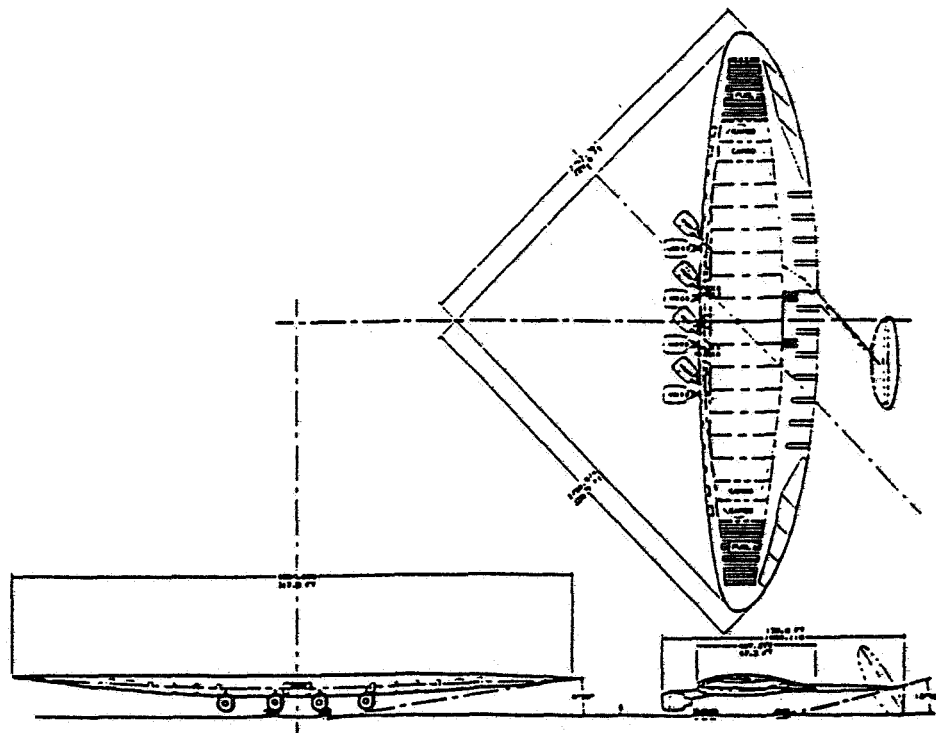
Figure 17 The OAW as a Subsonic Transport

In their second study⁹, McDonnell-Douglas developed a generalized computer model for the OAW aircraft, and evaluated two flight Mach numbers — 0.85 and 1.3. They found that the economics of the OAW drove them to airplane designs with large payloads. For the detailed design study, a payload of 800 passengers was selected for both vehicles.

The Mach 0.85 transport pictured below is designed for a range of 7000 N.Mi. The general arrangement is similar to that defined in the Boeing study with four forward pylon mounted engines, and a four-poster landing gear. The centerline wing chord is 67.3 feet, and unswept wing aspect ratio is 6 which results in a wing span of 317 feet. The engines are conceptual ADP (advanced ducted prop) engines with a sea level design point bypass ratio of 21.9.

The most obvious deviation from the OAW designs studied previously in this project is the addition of a boom-mounted stabilizer. During unswept flight at low speed the stabilizer is rotated to the horizontal position so that it functions as a horizontal stabilizer with elevator control. During high speed flight, the stabilizer is rotated to the vertical position as shown in the side view below. This permits it to provide a yawing moment to counteract the fundamental tendency of the OAW to yaw toward zero sweep angle. There are good reasons to have the boom mounted stabilizer from the standpoint of control, but there are structural and aerodynamic drag problems which have not been evaluated.

The taxi bump case which was found in the NASA studies to size the structure was not evaluated in this study. With a relatively narrow gear track, and with payload and fuel further out toward the wing tips, this could be a serious problem. If so, smaller payloads would be desirable to reduce the span of the cabin and move the fuel tanks closer to the landing gear.



General arrangement of Mach 0.85 OAW.

Figure 18 Ground Tests of the Stanford 20' Subsonic RC Model

Before committing to flight tests, a low risk method of ground testing was developed by Stanford. The aircraft designed for flight was mounted on a ground vehicle (a Volkswagen Scirocco with a sun-roof). The mounting was a shaft bolted to the car with a universal pivot on top attached to the airplane at the center of gravity. The arrangement is shown in the pictures on the following page. When the ground vehicle is driven at flight speeds, in this case up to 40 mph, the aircraft experiences aerodynamic forces and moments identical to those experienced in flight, and it is free to pivot in roll, pitch, and yaw. There is the additional force on the aircraft due to the interaction with the vehicle vertical motion. As a result, controlling the aircraft in a ground test such as this is considered more difficult than control in flight.

Two important discoveries during these tests which proved to be vital to the subsequent flight test:

- Initially, the model was designed with a static margin of 7% unstable to match the planned design of the full scale OAW. Ground vehicle tests of the 20' model demonstrated that the servos were too slow to permit this level of instability. The custom servos required to meet the necessary bandwidth requirement were beyond the timescale and budget of the project so the C.G. was moved forward reducing the level of static instability to 1.8%. The aircraft's open loop motion is still a very fast 0.5 second time-to-double, and an active control system is vital for flight.
- It was discovered that the engines caused an excessive pitching moment because the thrust line passes below the aircraft C.G. The ground vehicle test performed with both engines at full throttle showed that the thrust-dependent pitching moment easily overpowers the trim capability of the control surfaces. By mounting deflecting vanes in the engine exhaust, the engine thrust could be made to act through the aircraft C.G. thus eliminating the thrust dependent pitch moment, at a small loss in axial thrust.

(continued on following page)

**Figure 18 Ground Tests of the Stanford 20' Subsonic RC Model
(cont.)**

A final round of ground vehicle tests were carried out to verify the stability and trim settings of the model. The controls were adjusted so that the aircraft would be trimmed at 10° angle of attack, 35° sweep, and have zero rolling moment.

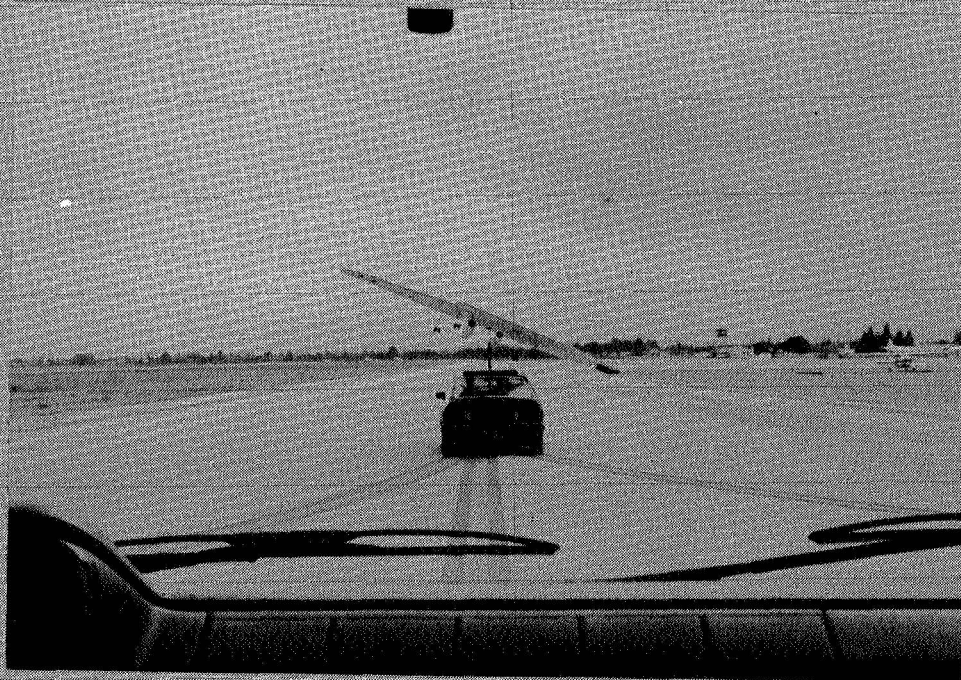


Figure 19 Flight Tests of the Stanford 20' RC Model

A four minute flight was completed above the Moffett Field runways in May, 1994. The flight began with a 23 second takeoff roll where the aircraft accelerated to 45 mph and then lifted from the ground after the pilot rotated the airplane with a pitch up command. The model climbed to an altitude of 150 feet and entered into a left hand pattern with speeds as low as 25 mph and as high as 65 mph with the wing sweep held constant at 35°. During the second left pattern the wing sweep was increased briefly to 50°, and at the end of this pattern the model landed safely on the runway centerline. This remarkable flight was watched by many nervous people from Stanford and NASA Ames, and the success of the flight and the whole RC model program is a testimonial to the model designer, builder, and pilot Dr. Steve Morris and his collaborator Dr. Ben Tigner. The flight test verified the aerodynamic analyses done for the model and the results determined from ground testing. An extensive flight test program was planned, but unfortunately budgetary constraints limited the flight testing to a single flight.

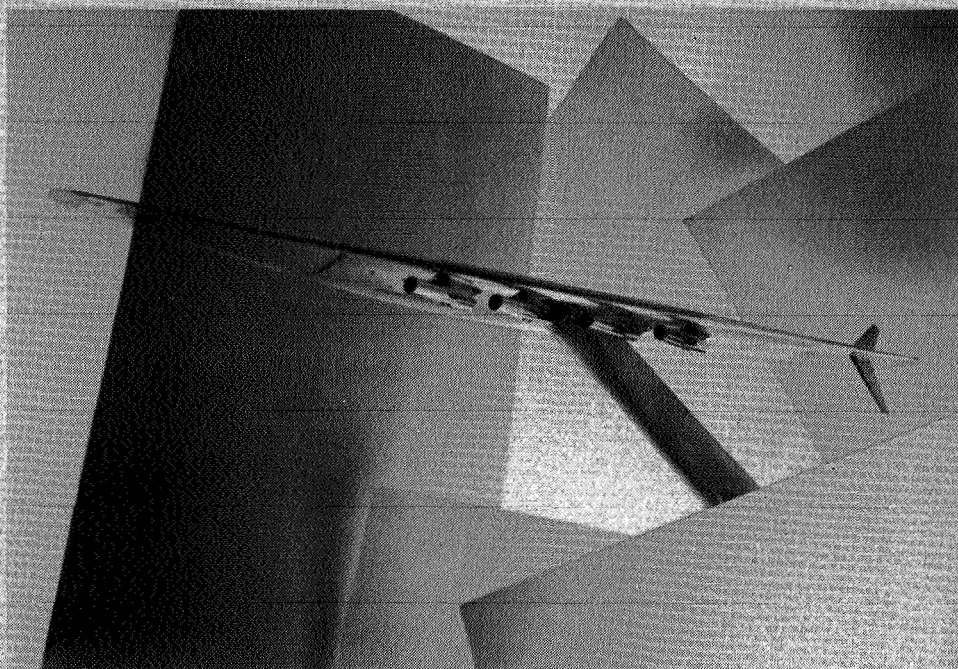


Figure 20 Wind Tunnel Test

A wind tunnel test was conducted on two models both having wing spans of 7.5 feet. These tests were conducted during June-July, 1994, in the NASA Ames 9 by 7-ft Supersonic Wind Tunnel. One model was designed to match the final configuration developed at NASA Ames, and the second model was a design developed at McDonnell-Douglas. An impressionistic view of the Ames model is given below, and as can be seen, the model is configured with both vertical fins and nacelles. Tests were conducted with the clean wing, with wing and fins, with wing and nacelles, and with wing, fins and nacelles. The second model had an elliptical planform and was tested as a clean wing only.

The test conditions included Mach numbers from 1.56 to 1.80, unit Reynolds numbers from 1.0 to 4.5 million/foot, and angles-of-attack from 0° to 6°. Because this work was concerned primarily with cruise performance, only a single sweep angle of 68° was tested. Force and moment data were obtained from a specially designed "flat" balance and surface pressure data from taps and pressure sensitive paint. A coordinated series of Navier-Stokes calculations for the bare wing and for the wing-nacelle-fin configuration, with and without blade support, was performed prior to the test. The quality of agreement obtained between the calculations and the test, observed in both surface pressure comparisons and the forces and moments, was very good.

There was an interesting sidelight to the test. A new scheme for interacting with wind tunnel users (termed "Remote Access Wind Tunnel") is under development at NASA Ames, and a prototype application of this digital network-based technology was successfully demonstrated during the test. A three-way video-conference was established among the interested parties at NASA Ames in Moffett Field, Boeing in Seattle, and McDonnell-Douglas in Long Beach to keep them apprised of test progress and to allow them to provide feedback on results. The interaction featured "live" audio, video, and shared access to a whiteboard, and it was supplemented by near realtime transfers of reduced data in a format suitable for plotting. This form of remote collaboration shows great promise: it was convenient, effective, and inexpensive.



CONCLUDING REMARKS

The work on the Oblique All-Wing supersonic transport outlined in this presentation is best described as an ad-hoc project at the Ames Research Center which evolved over the four year period from 1990 to 1994. An exception was the wind tunnel test. Once the decision was made to proceed with the test, careful plans were made and followed to design and build the models in time to meet the scheduled entry into the tunnel. The overall sequence of events that took place is probably very typical of the promotion of new technical ideas particularly when the concept involved is intended to improve on existing, well established configurations. The project was marked by strong advocacy on the part of dedicated proponents and sharp criticism on the part of numerous people within and without of NASA. This too is to be expected, and in the long run it is an important part of the process. Proponents must develop sufficient technical and economic data to defend their claims and justify continued development.

As outlined in the Introduction, this project was stimulated by a proposal from Stanford University to build and fly small scale radio control models to evaluate low speed stability and control issues. Before agreeing to fund this proposal, NASA Ames conducted an in-house systems study to evaluate the technical and economic viability of OAW aircraft as a supersonic commercial transport, and initial results were very promising. However, many technical issues including stability and control were identified, and along with agreeing to proceed with the Stanford proposal, the extremely important step to involve the aerospace industry was undertaken.

Boeing Commercial Airplane Company personnel argued strongly that details of the configuration must be carefully evaluated — layout of the cabin interior and integration of the landing gear were two items they emphasized. A contract with Boeing resulted in a configuration that identified geometric considerations of the OAW which lead to a clear understanding of the required size of the wing section in the region of the cabin. They also emphasized the need to understand the interface between the OAW aircraft and the airport. Boeing studied this problem as well, and clearly the airplane and the airports of today are not a good match. To reject the OAW transport on this basis alone is not justified. However, it is apparent that wider runways and greater separation between runways and taxiways are desirable and perhaps mandatory for the operation of the OAW transport.

The keys to OAW performance gains are improved cruise lift-drag ratio and reduced airplane empty weight due to the distribution of weight over a great portion of the wing span — the effect of span loading. The evaluation of the cruise aerodynamics was a major effort both at NASA Ames and in the contract with McDonnell-Douglas. Both organizations conducted extensive CFD studies, and two 7.5 foot models were designed and tested in the Ames 9 by 7-ft Supersonic Wind Tunnel. Although results have yet to be finalized, it is apparent that cruise performance is less than the original estimates by both Stanford and NASA Ames for a passenger carrying configuration. The need for a thicker wing section, trim drag effects, and nacelle wave drag and interference all contribute to reduced aerodynamic performance.

Understanding the potential weight benefit of the OAW transport remains a major shortcoming of the studies. Dr. Robert Liebeck of the Douglas Aircraft Company pointed out early in the project that an accurate model of weights is mandatory for any aircraft sizing studies. There is virtually no weights data base to turn to for this type of aircraft, and a detailed structural design study is required. This has not been done, and as a result further refinement is needed to properly size the aircraft as a function of payload size and range for different cruise Mach numbers. Any future work on OAW studies should give a structural analysis the highest priority.

Stability and control issues, the original impetus for the project, remain in spite of excellent work at Stanford, McDonnell-Douglas, and in-house at NASA Ames. An important point is that no "show stoppers" related to stability and control have been identified. In their evaluation of a subsonic version of the OAW, McDonnell Douglas opted for a boom mounted stabilizer for low speed pitch control and high speed yaw control. This would certainly not be appropriate for supersonic flight, but the fact that such a stabilizer has been proposed at this time highlights the need for continued stability and control work.

Beyond the documentation of the recent wind tunnel test results, there are no current plans within the NASA to continue this project. The following statements provide a brief summary of the OAW status as a result of this project.

- A baseline OAW configuration for carrying 400 - 500 passengers at a cruise Mach number of 1.6 was defined including the planform geometry of the wing which has an aspect ratio of nominally 10, the cross section geometry of the wing required for passengers, provision for ingress and egress, and the location of vertical fins, engines, landing gear, fuel tanks, and sub-systems.
- Problems in the interface between the aircraft and the airport were identified, but not solved. Introduction of an OAW transport would likely dictate some changes in airport design.
- The aerodynamic performance of the OAW at supersonic Mach numbers between 1.5 and 1.8 was developed in some detail both through CFD analyses and wind tunnel test. Initial estimates of very high lift-drag ratio at a flight Mach number of 1.6 have proven to be overly optimistic because the effects of nacelle and vertical fin integration were not properly identified. Without question there is room to improve the integration of the nacelles with the wing and thereby regain some of the lost aerodynamic performance. It is likely that a flight Mach number of 1.6 is an upper limit for an OAW transport, and lower cruise Mach numbers may be desirable. A subsonic OAW transport remains a possibility.
- Important structural loading conditions have been assessed but there is insufficient analysis to establish the weight of the OAW primary structure. It is apparent that pressure loads rather than bending loads are dominant in flight. On the ground, the bending loads during a taxi bump will be severe if the wing span is large with respect to the gear track. A wide gear track would provide a much better distribution of the landing gear loads, but this will require wider runways — a prospect that should not be discounted.
- Economic analyses have demonstrated that the OAW is most attractive for a large passenger capacity, nominally 800 passengers. However, this level of payload drives the airplane to a large size — particularly span which aggravates the airport interface problem. In addition, a large span may aggravate structural requirements as discussed above. Thus, there is insufficient data to establish a "best" payload size.
- The important stability and control issues have been identified through analysis and subsonic scale-model flight test, and no "show stoppers" exist. However, there is much work to be done to understand all the important effects such as aeroelasticity and gust sensitivity.
- The OAW transport has the potential for good to very good takeoff noise characteristics.

In retrospect, there are lessons to be learned from the OAW project that go beyond the pure technical results, and they apply to the evaluation of any proposed advanced concept, particularly one that must interface with an existing infrastructure and compete with well developed subsonic jet transports.

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A Corporate Supersonic Transport

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September 26, 1995**

**Transportation Beyond 2000:
Engineering for the Future**

September 26-28, 1995

A Corporate Supersonic Transport

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Introduction

Business aircraft manufacturers have been well rewarded in the market place for responding to technology, and thereby improvements in performance. Notable examples include the transitions to turboprop and turbojet aircraft as evidenced in the Gulfstream I and Learjet aircraft. The businesses that capitalized on these transitions were well rewarded.

No doubt over the past twenty years some have given considerable thought to a Corporate Supersonic Transport (CST). Gulfstream has, with the announcement of such an aircraft at Farnborough in 1988 and their 1991 announcement of a joint venture with Sukhoi to this end. Their market research indicated a substantial market for a 4000 nautical mile CST at \$60 million per aircraft.

This is a considerably different market than that for a commercial airline supersonic transport. In the second author's AIAA Durand Lecture,¹ he conjectured that for a supersonic transport to be economically successful, it would need to fly no more than Mach 1.5 - 1.6 and have the majority of its seats in business and first class. If it were to serve the growing international market for leisure travel, it would need to be an all wing aircraft flying obliquely, as suggested long ago by Lee² of Handley Page as a design for what became the Concorde. Careful studies by two design teams support these conjectures. A notable exception here are the very detailed studies by the Boeing Company.

The business market of interest here is smaller and better served by speed and airport flexibility. Overlooked in the Durand lecture was an aircraft he had considered long ago³ when seeking designs that might have a sonic boom that would be acceptable in overland flights, namely, a corporate supersonic transport. By 1970 the SR-71, with a nominal sonic boom overpressure of one pound per square foot, had been flying over selected areas of the western US for some time. Complaints about these unannounced flights were few.

This paper derives from a carefully considered study of the possibility of a corporate supersonic transport, conducted largely by the first author. It presents the non-proprietary aspects of a possible Corporate Supersonic Transport (CST). Such a CST could begin service as early as 2000. This project will require considerable technical assistance from NASA. Over a ten year production period this aircraft could accrue some \$15 billion in sales, with perhaps 40% of this amount being export sales.

Contents

The authors describe here, in brief, the strategies for developing a commercially successful CST, describe the potential market for such a business aircraft and the technology selected for its development. They then describe such an aircraft and delineate some missions for it.

The principal “show stopper” would seem to be the FAA certification of such an aircraft. The development of noise certification specifications for take off, and possible supersonic flight overland routes, are crucial to launching such an aircraft.

The authors conclude by suggesting some important roles for NASA in the development and eventual success of such an aircraft. We would note here that the roles NASA should play were well delineated by aircraft category nearly 15 years ago.⁴ As civil supersonic aircraft go, the CST is “smaller, faster, cheaper.”

Strategy

Several strategies underpin this aircraft. One derives from the recognition that there are a considerable number of corporations as well as governments for which the opportunity to invest time elsewhere can bring a very considerable return in economic or political benefit. In addition, these opportunities are frequent and the number that can be capitalized on depends, to a considerable degree, on the speed of transportation available to these individuals. This is not speed at any cost, but speed with a high economic or political return.

A second strategy derives from the recognition that there is excess aircraft production capability among US defense contractors and that some of these have achieved extraordinarily efficient production.

Third, an “open skies” policy in this country makes business aircraft operations inexpensive and the development of a business aircraft less problematic here than elsewhere.

Fourth is the long US history of supersonic flight and an enormously rich technology base supporting it. That is not to say that the twenty years of commercial Concorde operations do not provide others with a very considerable base of experience. They do. Indeed, we are told the Concorde has more supersonic flight hours than all other aircraft, world-wide, combined. But this experience is less diverse, being limited to a relatively large transport based on the technology of the late 1950s.

While technological improvements continue, and a new aircraft should plan to eventually accommodate some, only well established technology should be used in an aircraft that pioneers certification in a new flight regime.

The Market

For FY 1993, the number of general aviation flights across the Atlantic alone was estimated to be 20,000.⁵ Forty percent of the NBAA member companies fly to Europe. A comparable percentage flies in the Pacific and to Asia. Over seventy percent fly to the Caribbean and Central America. Thus, there is a considerable market for a long range, high speed, business aircraft.

It seems to us very reasonable to assume a CST will garner at least 15% of the long range business fleet. This means more than 300 aircraft for corporate use alone. This, augmented by government travel, suggests a \$10 to \$15 billion dollar market if such an aircraft were available today. It is not. But the proposed CST easily could be available by the turn of the century.

Market - 2000-2010

- Long Range & Mission-Enabled Applications
- 20,000 Atlantic Crossings/Year - Today
- 1/3 Projected Overland Usage
- Expand / Share Aircraft Long Range Fleet
- Corporate - 300+ Units
- Government / Special Mission - 50+ Units
- \$10-\$15 Billion Potential Market

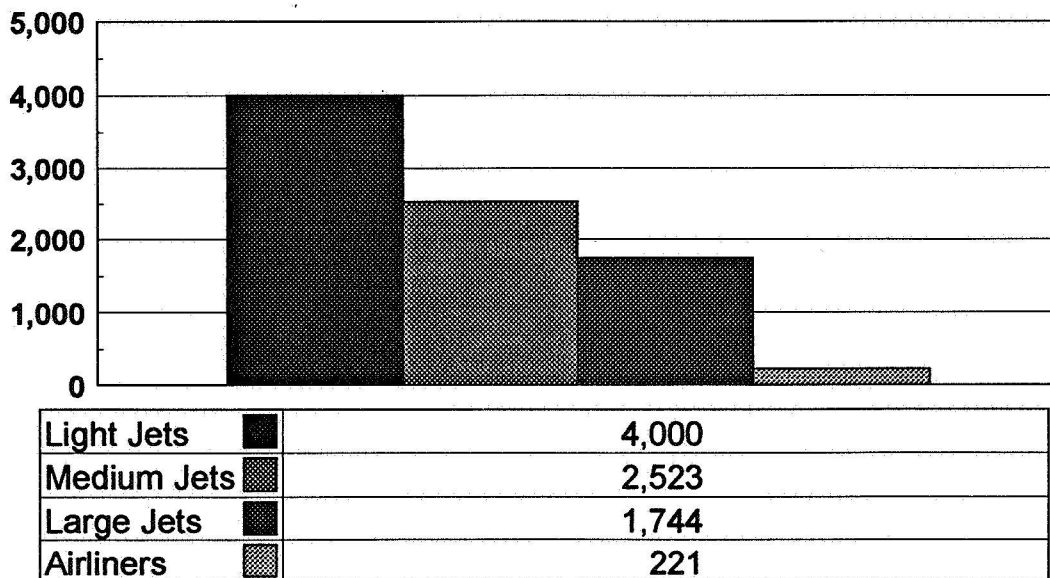
US Business Jet Fleet

The US business jet fleet comprises some 8500 aircraft, and over half of these are of medium size or larger. The world-wide fleet is thought to be about 1400 aircraft, with a similar distribution in size.

For short flights, speed is not crucial. But it becomes important at longer ranges, which now require longer duration flights. Range is not the crucial ingredient here; time is. Some business jets will soon be capable of 6500 nautical miles. But at their speeds, this is a very long trip. An aircraft capable of the same distance, with a stop, in half the time has, we believe, considerable advantage.

Corporate fleet business travel continues to grow rapidly. The largest growth rate in business transport is for international travel. As world markets become increasingly international, an even larger fraction of business travel will occur in private aircraft.

Business Jet Fleet



Source: AvData, 1995

The US Long Range Fleet

The US long range business fleet is some 2000 aircraft. World-wide this business fleet may be well over 3000 aircraft. Ninety percent of the National Business Aircraft Association (NBAA) owners use their aircraft for international flights. These trips would benefit greatly from increased speed. Any substantial increase in speed requires supersonic flight with the dual considerations of wave drag and sonic boom. The first of these compromises range; the second, if too large, would limit the available routes.

In this regard, two three-hour legs plus an hour long stop are much preferred by long range travelers than a twelve hour trip. We suggest that a CST will need to be two or more times faster than its subsonic competition for the value of time to offset the cost of this speed.

Long Range Fleet (> 3,000 nm)

- | | |
|------------------------------------|----------------------------------|
| ■ <i>Corporate Aircraft</i> | ■ <i>Airline Aircraft</i> |
| – Gulfstream II/III/IV | – B707/727/737 |
| – Falcon 50/900 | – DC8/9 |
| – Canadair Challenger | – BAC 111 |
| – IAI 1125 Astra | – Others |
| – Hawker 1000 | ■ 200 + Aircraft |
| – Others | |
| ■ 1,800 + Aircraft | |

The Technology

The technology in the proposed aircraft includes well established aerodynamics, a known engine, and current materials.

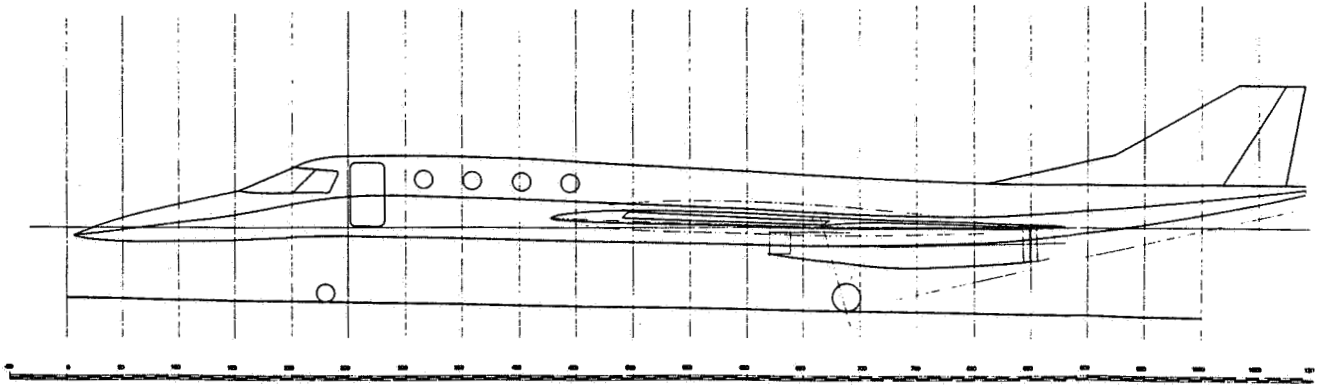
The cranked arrow wing planform is used most successfully on the F16XL. Natural flow wing design,⁶ an intuitive approach to area ruling, improves lift to drag. Aircraft shaping to minimize the equivalent perceived noise of the sonic boom frequently does this too. Minimum sonic boom perceived noise shapes are not minimum wave drag shapes, but they are often lower in wave drag than those now considered.

Technology

- **Aerodynamics**
 - Cranked Arrow Wing Planform
 - F16XL
 - Natural Flow Wing Design
 - Sonic Boom Shaping
- **Propulsion**
 - AlliedSignal F125-GA-100
 - ROC IDF
- **Materials - Current Technology**

The Aircraft

The first author's studies and knowledge of this market suggest that an eight to ten passenger aircraft with a nominal range of 3,350 nautical miles at Mach 1.8 would have considerable demand. Such an aircraft can capitalize as well on a higher speed for a shorter distance. The aircraft under current study is called the CST - 104A. It is the fifth iteration in our studies. Routes may be restricted by its sonic boom and, consequently, its range at near sonic Mach numbers is important.



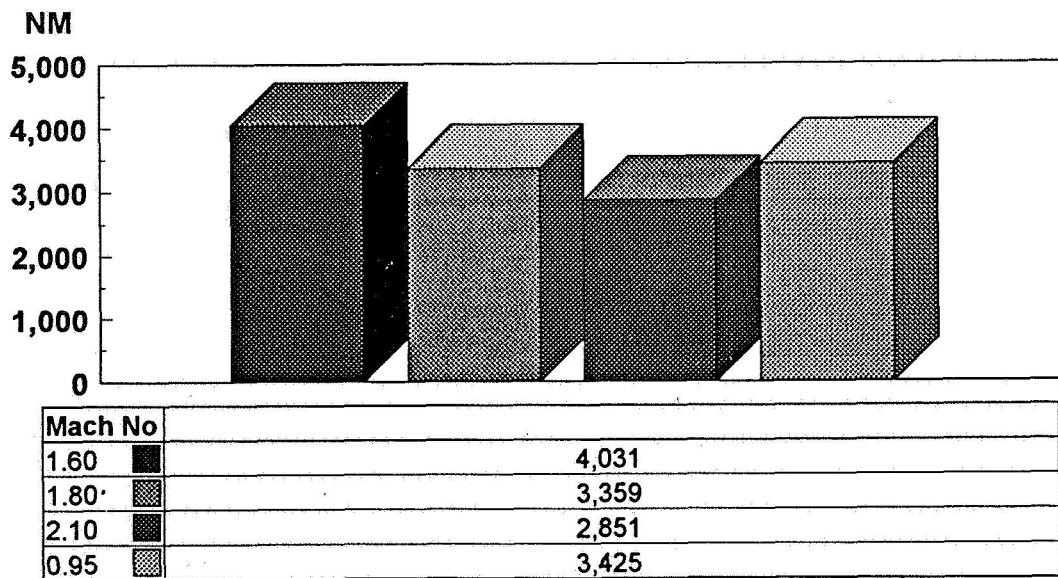
CST - Configuration 104A

- 8 - 10 Passengers (1,800 lbs)
- 3,350 nm Normal Cruise Range
- Mach 1.8 Normal Cruise Speed
- Speed / Range Flexibility

Speed and Range

Slower supersonic speeds provide longer ranges. At the 104A's maximum speed, corresponding to a Mach number of 2.1, its range is 2,850 nautical miles. At a Mach number of 1.6 it is just over 4,000 nautical miles. At $M = 0.95$, its range is 3,425 nautical miles, exceeding that at its $M = 1.8$ supersonic design point.

Speed vs Range



Size and Weight

The current configuration is 91 feet long and has a maximum takeoff gross weight of 66,000 pounds. This provides adequate space for eight to ten passengers plus crew. It would enter cruise above the tropopause with a weight of about 60,000 pounds. For this configuration the weights have been studied carefully.

Weights (lbs)

Structures	13,900
Propulsion	7,300
Systems & Equipment	5,100
Empty Weight	26,300
BOW	27,000
Payload	1,800
Max Zero Fuel Weight	28,800
Max Fuel	37,200
MLGW	37,200
MTOGW	66,000

Dimensions (ft)

Length	91
Height	18
Span	42
Fuselage Diameter (max)	6.5
Fuselage Fineness Ratio	14
Cabin Length	22
Cabin Width (max)	5.7
Cabin Height (max)	6.0
Cabin Volume (ft ³)	750

Sonic Boom

The connection between bodies of revolution with minimum wave drag for a given base area,⁷ volume and caliber,⁸ and three-dimensional aircraft was probably first recognized by Wallace Hayes in his 1946 CalTech Ph.D. thesis. But it only became clear with the 1955 NACA TN by Lomax.⁹ The aircraft shapes that minimize various sonic boom signature characteristics have been known for more than twenty years.³ The area distributions for minimum wave drag and those for various minimum sonic boom characteristics are not widely different. Thus a high L/D and low sonic boom are consistent with one another.

If the approximately 90 foot CST-104A begins its Mach 1.8 cruise at an altitude of 50,000 feet at a weight of 60,000 pounds, then, through careful design,³ its sonic boom overpressure could be as low as 0.4 pounds per square foot. It is lower at a lower Mach numbers, almost independent of cruise altitude (over the range 40,000 to 60,000 feet), increases nearly linearly with aircraft weight, and decreases nearly linearly with aircraft length.

Minimum Positive Phase Sonic Boom Overpressures

Overpressure lbs/ft ²	Weight lbs	Length ft	Altitude ft	Mach No
0.356	60,000	90	50,000	1.5
0.393	60,000	90	50,000	1.8
0.416	60,000	90	50,000	2.1
0.340	50,000	90	50,000	1.8
0.442	70,000	90	50,000	1.8
0.436	60,000	80	50,000	1.8
0.354	60,000	100	50,000	1.8
0.395	60,000	90	40,000	1.8
0.392	60,000	90	60,000	1.8

Seebass criterion; $W/L^{1.5} < 100$, $M < 1.6$, then overpressure can be less than 0.5 lbs/ft²

Mission

In a maximum range cruise mission at Mach 1.8, the aircraft needs only 24 minutes to cruise altitude and speed. It cruise-climbs for 2 hours and 45 minutes and then spends 32 minutes decelerating and landing, for a total flight time of 3 hours and 45 minutes to travel 3359 nautical miles. The average speed is about 90% of its cruise speed. Thus, for simple mission studies, we may approximate the time of travel using the cruise speed at the Mach number selected.

Mission Integration Summary - Mach 1.8 Cruise

Block	Altitude	KTAS	GW	Fuel	Range	Time
Start, Taxi, Takeoff	0	250	66,090	673	0	:11
Climb To Trop	36,089	556	65,417	2,598	69	:10
Supersonic Climb	43,998	1,032	60,976	1,843	43	:03
Cruise	46,890	1,032	36,063	24,913	2,912	2:49
Deceleration	46,890	688	34,617	1,446	229	:16
Descend / Land	0	250	33,944	673	104	:16
Total		941		32,146	3,359	3:45
Divert	43,827	545	30,671	3,274	200	:39
Loiter	15,000	325	28,840	1,831	0	:30

City Pair Missions

We depict here 8 city pair missions and approximate the travel times. The choice of Mach number is dictated by the range required. These trips are then compared with the travel times for the leading subsonic contenders. Travel times are typically 1/2 to 2/5 those for the subsonic jets. Stops were assumed to be one hour.

CST vs Subsonic Jets

Depart	Arrive	CST	900EX	G-V	GXP
Chicago	Los Angeles	1:12	3:06	3:06	3:06
Boston	San Francisco	1:54	4:48	4:42	4:36
Paris	Montreal	2:48	7:06	6:06	6:00
Riyadh	Singapore	3:42	8:30	7:30	7:30
Moscow	Washington	4:30	9:48	9:48	8:42
Tokyo	New York	5:42	12:48	12:48	12:48
Seattle	New Delhi	6:48	15:30	13:30	13:36
Brunei	Washington	8:48	21:00	17:56	17:12

City Pairs - Range / Speed / Time

Depart	Arrive	Range	Stops	Mach	Time
Chicago	Los Angeles	1,485	0	2.10	1:12
Boston	San Francisco	2,310	0	2.10	1:54
Paris	Montreal	2,915	0	1.80	2:48
Riyadh	Singapore	3,615	0	1.70	3:42
Moscow	Washington	4,210	1	2.10	4:30
Tokyo	New York	5,650	1	2.10	5:42
Seattle	New Delhi	5,990	1	1.80	6:48
Brunei	Washington	8,175	2	2.10	8:48

Technology Opportunities

This aircraft would be a likely candidate for laminar flow control. Laminar flow control could improve its performance considerably and it seems unlikely to be adopted on its subsonic competitors. Thus the advantage would be long lasting. Incremental improvements would come from higher turbine inlet temperatures, improved inlets and diffusers, and better shaping (area ruling) for reduced wave and induced drag.

Technology Opportunities

- **Engines**
 - SFCs
 - Temperature Margins
 - Nozzle/Diffuser Improvements
- **Aerodynamic**
 - Laminar Flow Control
 - Mach L/D vs Overpressure

Certification

The CST could be the first supersonic business jet. And it could well be the first supersonic civil airplane since the Concorde. FAA airport noise and sonic boom criteria for supersonic aircraft are lacking. The CST differs from an HSCT in several ways. For example, its takeoff and landing profiles differ considerably from an HSCT. For the CST-104A, takeoff is accomplished without afterburner.

Will a relatively modest sonic boom overpressure allow overland flight? What about the location of the boom from the CST acceleration to cruise? While this local focused boom might be half the sonic boom of an HSCT, its placement in relation to populated areas will have to be considered. Our long time focus on large supersonic transports has left many questions regarding a CST to be answered.

Show Stopper - Certification

- Overland Supersonic Operations
 - What's Acceptable?
 - Performance Penalty for Sonic Boom Reduction
- Airport (FAR 36)
 - Takeoff 92 EPNdB
 - Sideline 94 EPNdB
 - Approach 98 EPNdB

NASA's Role and the Next Steps

NASA has the expertise to be of considerable help in identifying and clarifying the noise issues for supersonic civil aircraft over a very large range of sizes, from the CST to the HSCT. With some better clarity on these issues, NASA has the expertise to help solve the problems identified.

A CST built with current technology requires the transfer of this technology to the manufacturer, as well as considerable assistance with wind tunnel testing and flight research. This aircraft must have flight handling qualities similar to those of subsonic business jets if it is to succeed.

The bottom line: It is NASA's role to make the US first in supersonic business jets and, while second in supersonic airliners, to now make the US first in economically successful supersonic airliners. Both are a considerable challenge. A CST is around the corner; an HSCT is a long way off.

Conclusions

The 2000 -2010 market for a CST would seem to be at least \$10 to \$15 billion. A considerable portion, although not the majority, of this market is export sales. This market is responsive to speed because of the considerable benefits of this speed.

The aerodynamic, avionics, control, propulsion, and structural technology bases exist within NASA, and other government agencies, to build a successful CST. The 104A conceptual design of such an aircraft is well advanced, including three two-engine and two four-engine studies.

With NASA's and the FAA's help, especially through their clarification of noise issues, and through technology transfer and other appropriate assistance from the government, a technically and economically successful CST can be, and should be, built.

Conclusions

- **\$1+ Billion/Year**
 - **Export Market**
- **Market Will Respond to Speed**
- **Technology Exists**
- **Engine is Mature**
- **Conceptual Design Advanced**
 - **3 2-engine configurations**
 - **2 4-engine configurations**

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- ¹ Seebass, R., "The Prospects for Commercially Successful Supersonic Transport," AIAA Paper No. 94-0017.
- ² Lee, G.H., "Slewed Wing Supersonics," *The Aeroplane*, 1961.
- ³ Seebass, A. R. and George, A. R., "Design and Operation of Aircraft to Minimize their Sonic Boom," *J. Aircraft*, Vol. 22, No. 9. pp. 509-517, 1974.
- ⁴ *NASA's Role in Aeronautics: A Workshop*, National Academy Press, Washington, 1981.
- ⁵ *FAA Aviation Forecast, 1995-2006*, FAA-APO-95-1, March 1995.
- ⁶ Wood, Richard M, and Bauer, Steven X.S., "The Natural Flow Wing Design Concept," NASA TP 3193, 1992.
- ⁷ von Karman, Th. and Burgers, J.M., *Aerodynamic Theory*, W.F. Durand ed., Vol. 2, Springer, 1934.
- ⁸ Sears, W.R., "On Projectiles of Minimum Wave Drag," *Quart. Appl. Math.*, Vol. 4, No. 4, pp. 361-366, 1947.
- ⁹ Lomax, H., *The Wave Drag of Arbitrary Configurations in Linearized Flow as Determined by Areas and Forces in Oblique Planes*, "NACA RM A55A18, 1955.

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13. ABSTRACT (Maximum 200 words) The purpose of the workshop was to acquaint the staff of the NASA Langley Research Center with the broad spectrum of transportation challenges and concepts foreseen within the next 20 years. The hope is that the material presented at the workshop and contained in this document will stimulate innovative high-payoff research directed towards the efficiency of future transportation systems. The workshop included five sessions designed to stress the factors that will lead to a revolution in the way we will travel in the 21st century. The first session provides the historical background and a general perspective for future transportation, including emerging transportation alternatives such as working at a distance. Personal travel is the subject of Session Two. The third session looks at mass transportation, including advanced rail vehicles, advanced commuter aircraft, and advanced transport aircraft. The fourth session addresses some of the technologies required for the above revolutionary transportation systems to evolve. The workshop concluded with a wrap-up panel discussion, Session Five. The topics presented herein all have viable technical components and are at a stage in their development that, with sufficient engineering research, one or more of these could make a significant impact on transportation and our social structure.				
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